Public Interest Energy Research (PIER) Program
FINAL PROJECT REPORT

PUBLIC INTEREST ENERGY RESEARCH ADVANCED GENERATION ROADMAP

Prepared for: California Energy Commission
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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

The *Public Interest Energy Research Advanced Generation Roadmap* is the final report for the PIER Advanced Generation project 500-06-012, Work Authorization Number NCI-06-027-P-R conducted by Navigant Consulting. The information from this project contributes to PIER's Advanced Generation Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-4878.

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Abstract

The Advanced Generation Program is one of the key focus areas for the Public Interest Energy Research (PIER) Program. The program developed a roadmap to guide research, development and demonstration (RD&D) efforts through 2020, to support state policy goals and the vision of the PIER Advanced Generation Program. The roadmap includes eleven program milestones, distributed across three program areas: commercial combined heat and power/combined cooling heating and power, industrial cogeneration, and advanced gas turbine cycles. This roadmap report presents the roadmap, the milestones for achievement, as well as an implementation plan.

Keywords: Advanced generation, roadmap, distributed generation, combined heat and power, cogeneration, gas turbines, emissions

Executive Summary

The Advanced Generation Program is one of the key focus areas for the Public Interest Energy Research (PIER) Program. The program developed a roadmap to guide research, development and demonstration (RD&D) efforts through 2020. This report presents the roadmap, milestones for achievement, as well as an implementation plan.

Supporting Policies and Program Vision

The PIER Advanced Generation Program conducts RD&D that supports key California energy goals and policies. Significant California policy goals and directives guiding PIER Advanced Generation research efforts include:

- Install 4,000 Megawatts (MW) of additional combined heat and power capacity by 2020 (California Air Resources Board Assembly Bill 32 Scoping Plan).
- By 2012, repower aging power plants or retire and replace with cleaner technologies (*2005 Integrated Energy Policy Report [IEPR]*).
- Statewide greenhouse gas emissions will be limited to 1990-equivalent levels by 2020 (Assembly Bill 32 [Nuñez, Chapter 488, Statutes of 2006]).
- Serve 33 percent of retail electricity with renewable energy by 2020 (Governor's Executive Order S-14-08 [Renewable Portfolio Standard]).

A new vision statement for the PIER Advanced Generation Program enables the program to play a key role in helping the state meet these key policy goals. The 2020 PIER Advanced Generation Vision statement is:

> *The PIER Advanced Generation Program provides key RD&D that enables California to generate energy efficient, abundant, affordable, reliable, and environmentally-friendly electricity (and other forms of power) from small to large power plants, including distributed generation and combined heat and power, using clean non-renewable fuels and fuel flexibility capability to help reach the greenhouse gas emissions reductions targets.*

Program Roadmap

PIER Advanced Generation will focus on three key program areas: commercial combined heat and power/combined cooling, heating and power; industrial cogeneration; and advanced gas turbine cycles. The PIER Advanced Generation Roadmap is focused on eleven milestones for PIER Advanced Generation to achieve within these program areas, as well as cross-cutting milestones which address multiple program areas. The roadmap is intended to guide PIER Advanced Generation RD&D efforts to assist in achieving the program vision in 2020.

Each of the eleven program milestones helps achieve not only the program vision, but support important state policy goals, as well. The eleven top priority milestones are presented below, by program area.

Commercial Combined Heat and Power/Combined Cooling Heating and Power

1. Effective Building-Scale Integration of Thermally-Driven Chiller Combined Cooling Heating and Power System Demonstrated
2. Cost-Competitive Thermally-Driven Chiller for Combined Cooling Heating and Power Applications Demonstrated

Industrial Cogeneration

3. Impact of Alternative Fuels Use on Industrial Combined Heat and Power Systems Determined
4. Standardized, Fully-Integrated Industrial Combined Heat and Power Systems Demonstrated for Key Applications
5. Cost-Competitive Industrial Combined Heat and Power System Integrated with Energy Storage Demonstrated

Advanced Gas Turbine Cycles

6. Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated
7. Hybrid Renewable Cycle Systems Integration with Combined Cycle Plants Demonstrated
8. Fuel Cell-Hybrid Combined Cycle System Demonstrated

Cross-cutting Milestones

9. Fuel Flexibility Range for Key Distributed Generation Technologies Established
10. Cost and Performance Improvement Targets for Heat Recovery Technologies Demonstrated
11. Fuel-Flexible Combined Heat and Power Systems Powered by Key Distributed Generation Technologies Demonstrated

Roadmap Implementation Plan

The roadmap implementation process for the PIER Advanced Generation Program consists of four steps:

1. **Determining the approach to implement the roadmap:** This involves identification of research initiatives, development of budget plan, and establishing support mechanism for roadmap implementation by forming project- and program-level RD&D partnerships.
2. **Prioritize near-term goals in conjunction with the annual Work Plan:** This includes choosing high priority research initiatives based on the progress toward relevant policy goals, number of milestones to which a research initiative is applicable, timing, and partnership opportunities within PIER.
3. **Develop and release solicitations:** This means developing and issuing grant solicitations based on the research initiatives. Also it will identify cost-share partners as

appropriate, based on the anticipated size and the desired timeframe of resulting RD&D projects. Once winning proposals are chosen, the PIER Advanced Generation Program will work with the contractors to finalize the scope of the project, budget and schedule and establish agreements to conduct the projects.

4. **Evaluate roadmap progress:** The project results will be reviewed and shared with internal and external stakeholders, including relevant PIER and California Energy Commission staff, program advisory committee and other RD&D partners. Also assess any changes in policy and market needs that may influence RD&D priorities and objectives. Refine or modify the focus of the roadmap as necessary and appropriate.

To best align its RD&D portfolio with the rapidly changing industry landscape, PIER Advanced Generation will first conduct an assessment of the relevant market, regulatory and economic barriers in California to aggressive adoption of advanced generation technologies as it prepares to implement the Roadmap. This preparatory step will be essential in developing and prioritizing appropriate near-term research initiatives in order to ensure they have maximum benefit.

RD&D Stages for Advanced Generation Roadmap Implementation

Given the focus of PIER Advanced Generation Program, three types of RD&D activities emerge:

1. **Evaluation and Component Design:** The goal of this phase will be to develop and evaluate basic components required for target technologies to achieve a level of performance that is attractive to the market.
2. **System Design and Early-Stage Demonstration:** In addition to establishing technical viability of the target technology, RD&D effort in this phase will improve system performance of the technology (including cost performance) to match industry needs.
3. **Commercial-Scale Demonstration:** RD&D effort in this phase will demonstrate a commercially viable application of the target technology that meets specific technical and economic goals.

Draft Budget Plan

The PIER Advanced Generation Program has developed a draft budget plan based on the anticipated magnitude of RD&D efforts required to achieve a roadmap milestone, as well as the milestone's level of importance to state policy goals. The estimate for the PIER Advanced Generation budget assumes that the PIER Advanced Generation Program will contribute between 10 to 40% of the total estimated budget for RD&D.

Partnership Strategy and Recommendations

Successful implementation of a research roadmap will require strong RD&D partnership at both the project-level and program-level.

Project-level partners are entities that will work in tandem with the PIER Advanced Generation Program to execute, or support completing, RD&D projects. These partners may include technology providers (such as equipment manufacturers and engineering firms), local governments, research universities, national labs, and other technical experts.

Program-level advisors/reviewers are expected to provide expert insight, industry perspective and constructive guidance which will help the PIER Advanced Generation Program maintain its alignment with the program vision as well as the surrounding policy and market landscapes. Once the roadmap is finalized, the PIER Advanced Generation Program will convene a Program Advisory Committee as a channel to engage its expert advisors. To the extent possible, the PIER Advanced Generation Program will ensure that its Program Advisory Committee will include members who represent the Federal government, state government, utilities, and technology manufacturers.

Roadmap Progress Evaluation and Revision Process

The research roadmap is a dynamic document that will require regular refinement throughout its implementation process. Evaluation of roadmap progress involves critical review of available results from ongoing and completed RD&D projects with relevant stakeholders, including PIER/Commission staff, the Advanced Generation Program Advisory Committee, project-level RD&D partners and other key stakeholders. At the end of each evaluation, the PIER Advanced Generation Program will have clear direction on how to calibrate and refine the focus of its roadmap as necessary and appropriate.

1.0 Introduction

The California Energy Commission's (Energy Commission) Public Interest Energy Research (PIER) program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace. Senate Bill 1250 (SB 1250) directs the PIER program to ensure that the citizens of this state continue to receive safe, reliable, affordable, and environmentally sustainable electric service (Perata, Chapter 512, Statutes of 2006).

The PIER Advanced Generation program is one of eight program areas within PIER (Figure 1).

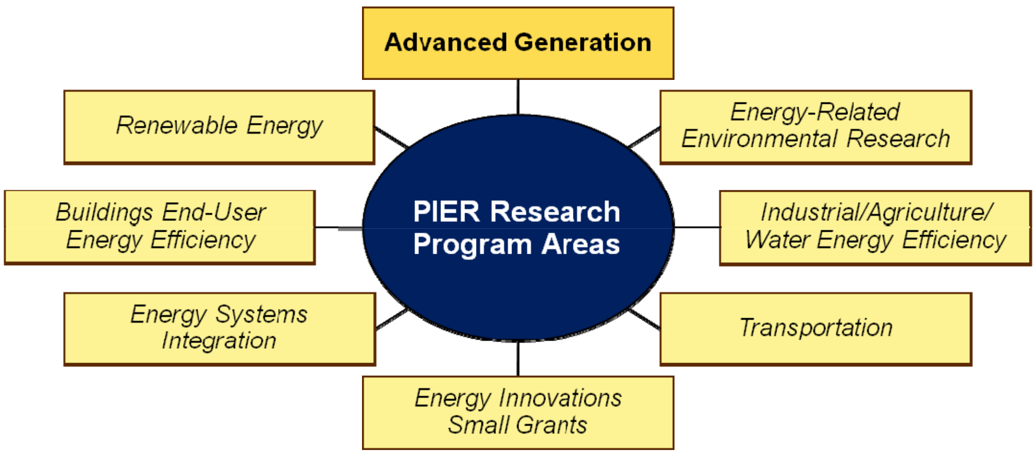

Figure 1. PIER Research Program Areas
Source: *Navigant Consulting, Inc.*

Under the guidance of SB 1250, PIER Advanced Generation funds research, development, and demonstration (RD&D) of advanced generation technologies for deployment in new applications and which exceed current performance (efficiency, environmental) and customer/user expectations (reliability, availability, affordability, maintainability, durability and usability). The primary focus areas of the program are non-renewable electricity generation resources in California, such as natural gas, and combined heat and power/cogeneration, but with appropriate context of oil, coal, and nuclear as well as renewable energy. Past PIER Advanced Generation research initiatives include the Advanced Reciprocating Internal Combustion Engines Collaborative, which seeks solutions for reducing emissions from internal combustion engine generation, as well as research on advanced generation technologies such as microturbines, fuel cells, and reciprocating engines.

PIER Advanced Generation links to several other PIER program areas:

- Building End-Use Energy Efficiency – combined heat and Power (CHP)/combined cooling, heat and power (CCHP) is a key technology category that addresses both the generation and supply-side energy efficiency objectives.

- Renewable Energy Technologies – Fuel flexibility of power generators and hybrid combinations of fossil and renewable energy are two of the key RD&D themes for PIER Advanced Generation. Furthermore, advanced generation technologies could help address the issue of intermittency associated with variable renewable resources and increase the adoption of renewable fuels as power sources.
- Industrial/Agricultural/Water End-Use Energy Efficiency – Key common RD&D themes include mechanical (e.g., evaporating cooling fan), thermal (e.g., CHP), and electricity for pumping water.
- Energy-Related Environmental Research – PIER Advanced Generation and PIER Environmental Area collaborate in developing approaches to improve environmental performance of generation technologies and technology solutions to reduce emissions.
- Transportation – Though different in application, technological advances in internal combustion engines, fuel cells and other prime movers could be leveraged by both PIER Advanced Generation and PIER Transportation (e.g., heavy-duty and public transportation vehicles, and plug-in hybrids vehicles).
- Energy Systems Integration – Flexible dispatchability of distributed generation (DG) is a crucial element of the Smart Grid in California, which must maximize the benefit of clean distributed energy resources (DERs).

PIER Advanced Generation Program conducts RD&D that support key California energy goals and policies. Significant California policy goals and directives related to non-renewable electricity generation, large-scale or distributed, are shown in Table 1.

Table 1. State Policies Guiding PIER Advanced Generation

Policy Focus Area	Policy Descriptions
Distributed Generation/Combined Heat and Power (DG/CHP)	• Install 4,000 Megawatts (MW) of additional CHP capacity by 2020 (California Air Resources Board [ARB] AB 32 Scoping Plan). • Use CHP so that new construction is net zero energy by 2020 for residences and 2030 for commercial buildings (*2007 Integrated Energy Policy Report* [*2007 IEPR*]).
Advanced Gas Turbine Cycles	• By 2012, repower aging power plants or retire and replace with cleaner technologies (*2005 IEPR*). • Phased elimination of once-through cooling between 2015 and 2021 (*2008 IEPR Update*). • New reliance on power plants with carbon dioxide (CO_2) emissions similar to those of a modern natural gas combined cycle power plant (greater than 1,100 pounds per Megawatt hour [MWh]) is prohibited (*2007 IEPR*, SB 1368).
Energy Efficiency and Environment	• Ensure that the citizens of this state continue to receive safe, reliable, affordable, and environmentally sustainable electric service (Senate Bill 1250 [Perata, Chapter 512, Statutes of 2006]). • Statewide greenhouse gas (GHG) emissions will be limited to 1990-equivalent levels by 2020 (Assembly Bill 32 [Nuñez, Chapter 488, Statutes of 2006]). • Reduce GHG emissions to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050 (Governor's Executive Order - S-3-05). • Serve 33 percent of retail electricity with renewable energy by 2020 (Governor's Executive Order S-14-08 [Renewable Portfolio Standard (RPS)]).

Source: *Navigant Consulting, Inc.*

A new vision statement for the PIER Advanced Generation Program enables PIER Advanced Generation to play a key role in helping the state meet these key policy goals. The 2020 PIER Advanced Generation Vision statement is:

> *The PIER Advanced Generation Program provides key RD&D that enables California to generate energy efficient, abundant, affordable, reliable, and environmentally-friendly electricity (and other forms of power) from small to large power plants, including distributed generation and combined heat and power, using clean non-renewable fuels and fuel flexibility capability to help reach the greenhouse gas emissions reductions targets.*

Keeping with this vision, PIER Advanced Generation would focus on improving efficiency and reducing GHG emissions of large-scale and distributed generation systems fueled with cleaner fuels such as natural gas and that are fuel-flexible. In particular, PIER Advanced Generation will focus on three key program areas: Commercial CHP/CCHP; Industrial Cogeneration; and Advanced Gas Turbine Cycles (Figure 2).

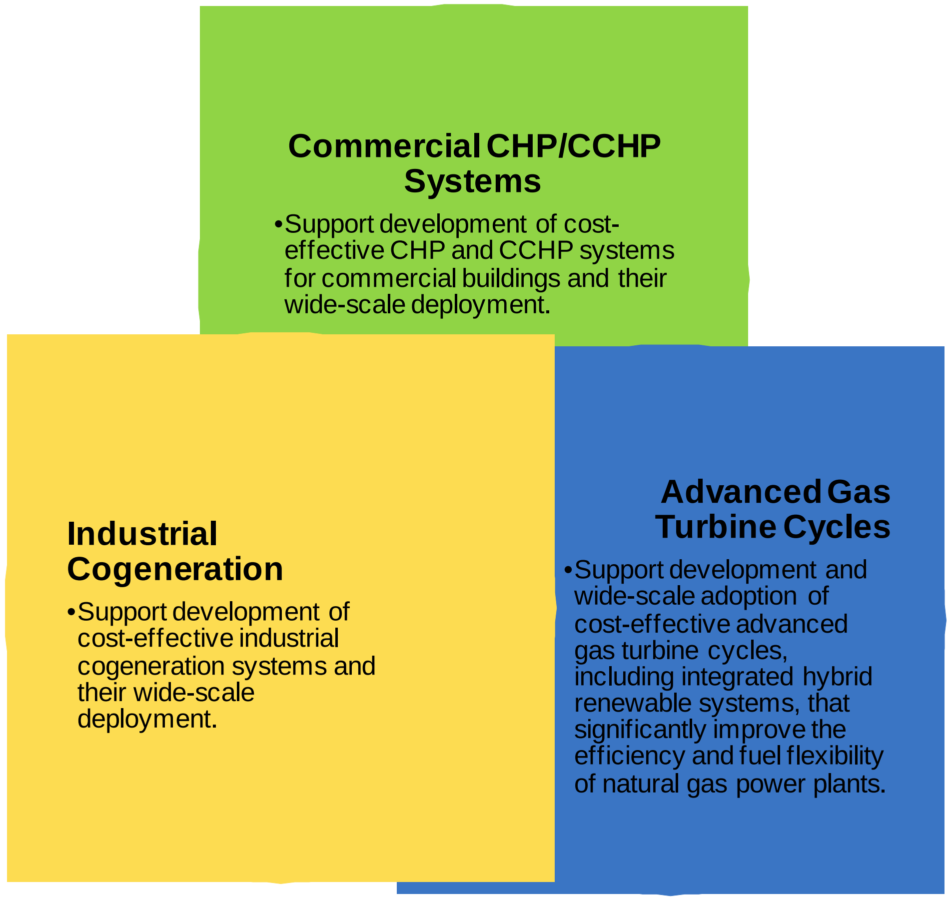

Figure 2. PIER Advanced Generation Key Program Areas

Source: *Navigant Consulting, Inc.*

The PIER Advanced Generation Roadmap is focused on milestones for PIER Advanced Generation to achieve within these key program areas, as well as cross-cutting milestones which address multiple program areas. The roadmap is intended to guide PIER Advanced Generation RD&D efforts to assist in achieving the program vision in 2020.

Investing in advanced generation technology provides an opportunity for developing reliable, affordable, secure, and sustainable power. Accelerating the replacement of inefficient power plants and expanding the advanced power generation development program to expand the baseload generation capacity to meet customer needs would further improve the environmental quality of the power generation sector in California. RD&D investments in the next generation of technology to ensure that customers have access to the latest, most advanced technologies is a critical part of the advanced power generation initiative. This should ultimately lead to commercialization of the next generation of cleaner generation technologies and to pursue advancement of next generation technologies through collaborations and partnerships with R&D and power generation entities.

2.0 Advanced Generation Roadmap

The PIER Advanced Generation roadmap is designed to guide RD&D over the next ten years to achieve the PIER Advanced Generation Program vision. The roadmap is shown in Figure 3 below.

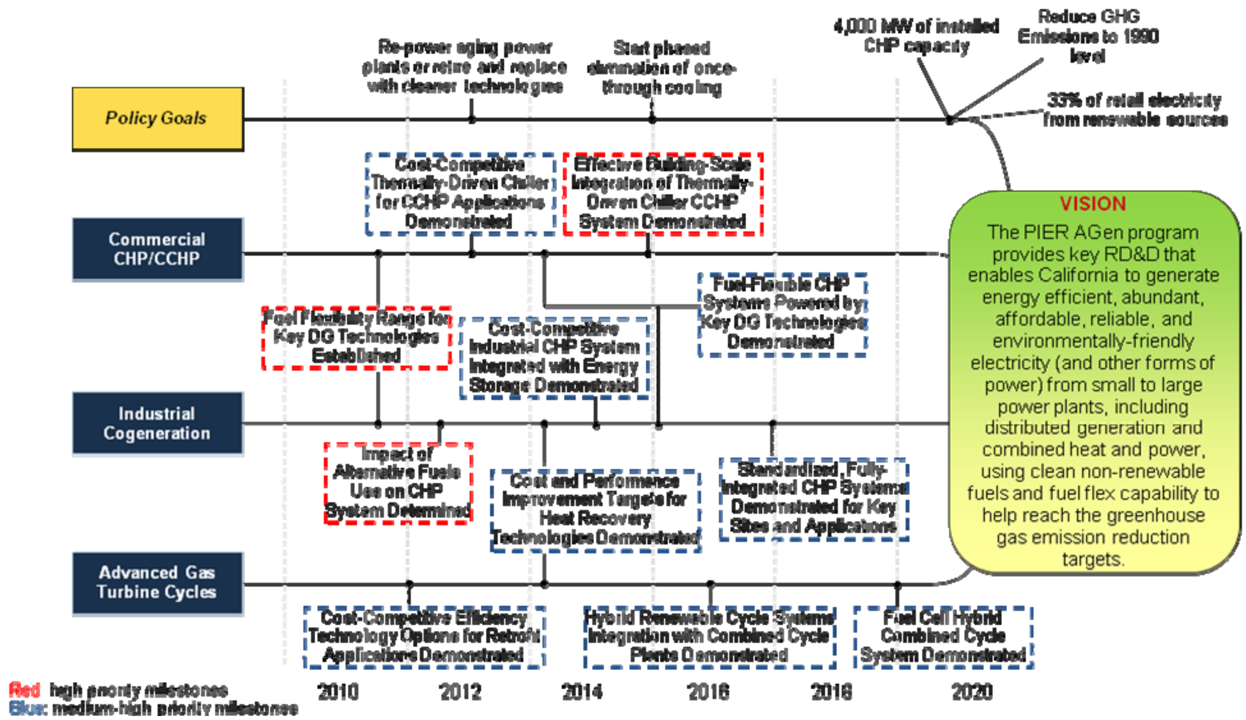

Figure 3. PIER Advanced Generation Program Roadmap

Source: *Navigant Consulting, Inc.*

As shown above, eleven milestones were developed to benchmark the program's progress. Each of the milestones describes a state of industry or technological development forecasted to exist at a given point in the future. These milestones signify achievement of not only the program vision, but also important state policy goals as well.

2.1. Roadmap Development Process

The roadmap was developed following the process outlined in Figure 4 below.

Figure 4. Roadmap Development Process

Source: *Navigant Consulting, Inc.*

First, the current status of 26 advanced generation technologies was reviewed in a background paper[1]. These technologies include reciprocating engines, microturbines, fuel cells, thermally-driven chillers, heat recovery, inlet cooling, and hybrid renewable cycles. Profiles of these technologies included recent R&D efforts, so that research gaps could be identified easily. Preliminary milestones were developed from the technology review process which covered a wide range of technologies and other R&D issues. The milestones were developed to lead to achievement of PIER Advanced Generation's program vision, and will assist PIER Advanced Generation in demonstrating that progress towards this goal has been made. There were 31 preliminary milestones identified which were grouped within the three PIER Advanced Generation Program areas: 11 within commercial CHP/CCHP, 10 within industrial cogeneration, 8 within advanced gas turbine cycles, and 2 milestones cross-cutting multiple program areas.

The preliminary program milestones were scored according to two criteria: level of importance and feasibility. These criteria are illustrated below in Figure 5 and Figure 6.

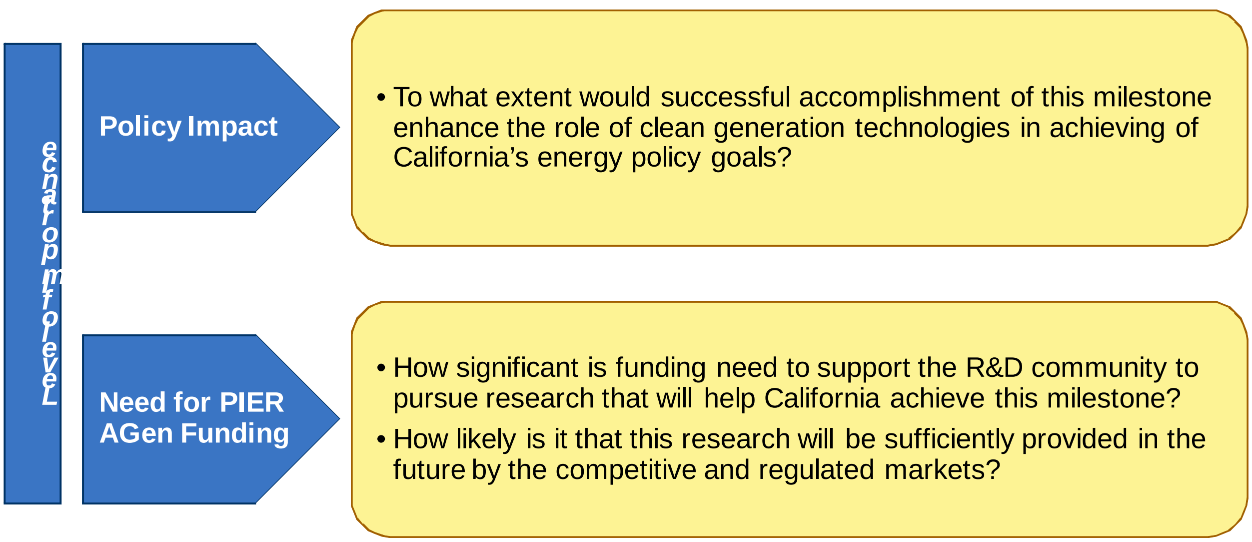

Figure 5. Level of Importance Criteria

Source: *Navigant Consulting, Inc.*

[1] Contreras, Jose Luis, David Walls, Erin Palermo, David Feliciano (Navigant Consulting, Inc.). *Advanced Generation Roadmap Background Paper, 2009*. California Energy Commission, PIER Program. CEC-500-2009-086.

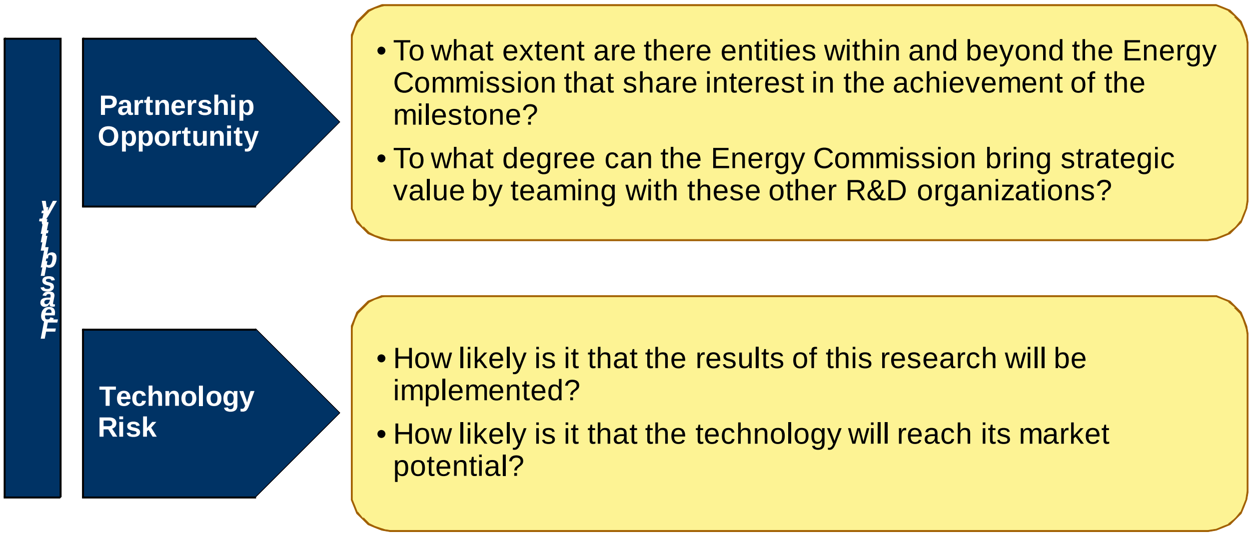

Figure 6. Feasibility Criteria
Source: *Navigant Consulting, Inc.*

After the scoring, milestones were ranked according to priority: low, medium, medium-high and high. Top priority milestones are those with medium-high or high priority rankings. The preliminary scoring and prioritization was shared with key technical reviewers across the advanced electric generation sector, including equipment manufacturers, equipment suppliers, government agencies, utilities, national labs, universities, non-profit/associations and beyond, as shown in Figure 7.

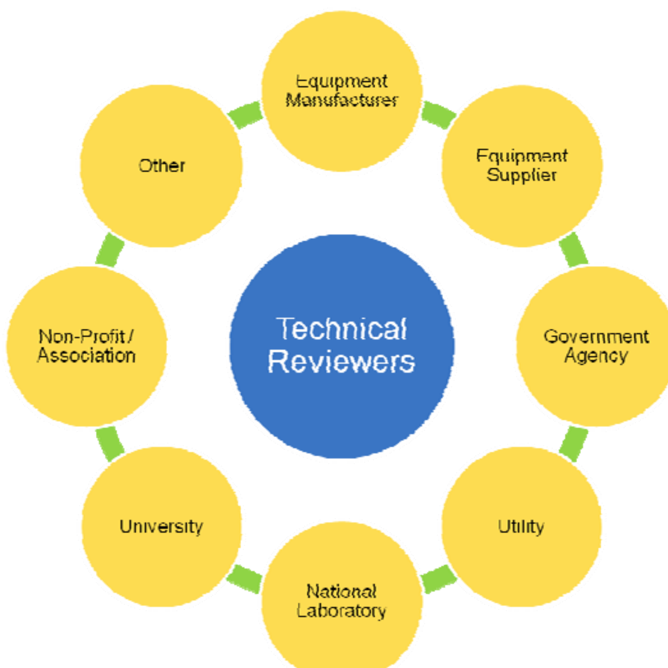

Figure 7. Technical Review Meeting Experts
Source: *Navigant Consulting, Inc.*

The reviewers gave feedback on the milestone ranking, and the prioritization was updated as a result. Following the technical review meeting, milestone prioritization was reviewed with PIER Advanced Generation staff, and eleven top priority milestones were finalized.

2.2. Roadmap Milestones

2.2.1. Milestone Descriptions

The eleven top priority milestones are presented below, by program area.

Commercial CHP/CCHP

1. **Effective Building-Scale Integration of Thermally-Driven Chiller CCHP System Demonstrated:**
   Demonstrate a commercial building-scale thermally-driven chiller CCHP system. This Demonstration will address current technology limitations, including high cost, minimum performance level in a range of ambient conditions, and integration with heating, ventilation and air conditioning (HVAC) systems commonly used in commercial buildings in California.
2. **Cost-Competitive Thermally-Driven Chiller for CCHP Applications Demonstrated:**
   Improve the energy and environmental performance of thermally-driven chillers to increase its appeal for commercial CCHP application in California. Approaches to reduce costs of thermally-driven chiller technology include creating incentive structures to support thermally-driven chiller CCHP systems, improving chiller efficiencies when paired with CHP systems, and optimizing the chiller design to typical ambient operating condition in California.

Industrial Cogeneration

3. **Impact of Alternative Fuels Use on Industrial CHP Systems Determined:**
   Demonstrate and determine the impact of alternative fuel use to operate industrial CHP systems. Alternative fuels will include a broad spectrum of renewable fuels, biofuels, digester gas, and synthetic fuels. Key considerations include modifications to prime movers, fuel handling and treatment, and fuel storage.
4. **Standardized, Fully-Integrated Industrial CHP Systems Demonstrated for Key Applications:**
   Demonstrate standardized, fully-integrated industrial CHP for applications in California. Key considerations include optimization to California's climate, key applications and associated usage patterns, cost reduction and ease of integration into existing facilities. This research should focus on key applications which are most prevalent in California's industry sector.
5. **Cost-Competitive Industrial CHP System Integrated with Energy Storage Demonstrated:**
   Improve the energy performance of industrial CHP system to increase its financial appeal through integration with energy storage. Demonstrate the viability of integration both electric and thermal storage technologies aimed at reducing costs of total CHP system to increase value proposition to end-users.

Advanced Gas Turbine Cycles

6. **Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated:**
   Analyze the costs and benefits of various retrofit technologies for advanced gas turbine cycle (e.g., cooling technologies, recuperators, recuperated gas turbines and heat recovery) in California. Evaluate and document the efficiency potential of these retrofit options, and assess its economic viability given their high capital cost.

7. **Hybrid Renewable Cycle Systems Integration with Combined Cycle Plants Demonstrated:**
   Demonstrate hybrid renewable cycle systems integrated with a combined cycle plant. This research may entail small-scale demonstration first to understand performance characteristics. This research will demonstrate the viability of integrating renewable resources into combined cycle plant operation. Given the abundance of solar resources in California, this research should focus on increasing the amount of solar share in hybrid cycles.

8. **Fuel Cell-Hybrid Combined Cycle System Demonstrated:**
   Design, develop and demonstrate a gas turbine combined cycle system optimized for hybrid application with a fuel cell system in the California market. Evaluate and demonstrate the technical feasibility and commercial potential of a fuel cell-hybrid combined cycle in the context of California's unique market, regulatory and environmental conditions. Key considerations include pollutant emissions performance of Gas Turbine technology (may adversely affect fuel cell performance), compatibility with performance parameters of fuel cell technologies (e.g., pressure ratios and mass flows), outlook for technology advancements for combined cycle systems to improve the compatibility with fuel cells.

Cross-cutting Milestones

9. **Fuel Flexibility Range for Key DG Technologies Established:**
   Determine the desired range of fuel flexibility for commercial and industrial DG and CHP/CCHP systems in California. Fuel flexibility will address a broad spectrum of renewable fuels, biofuels, digester gas, synthetic fuels and oxyfuel combustion. Prime mover DG technologies include the full range of technologies, including internal combustion engines, microturbines, fuel cells, external heat engines, stirling and gas turbines. Key considerations include the characteristics of most promising technology options for prime movers, availability of feedstocks for alternative fuels and availability of fuel distribution infrastructure. Evaluate different alternative fuel options for their technical and economic potential in commercial /industrial CHP application.

10. **Cost and Performance Improvement Targets for Heat Recovery Technologies Demonstrated:**
    Assess and establish the current state of heat recovery technology options for industrial CHP and power generation applications. Determine and demonstrate cost and

performance improvement targets for key heat recovery technologies especially relevant for California. A key parallel to be considered is the economics and operation of renewable generation; economics and operation of heat recovery technologies are similar to renewables project, in that they require large up-front investment and minimal fuel cost.

11. **Fuel-Flexible CHP Systems Powered by Key DG Technologies Demonstrated:** Demonstrate a fuel-flexible commercial/industrial CHP system powered by key DG technologies without significant degradation of energy and environmental performance. The demonstration should address current technology limitations, including high cost and minimum performance level over a range of ambient conditions.

2.2.2. Related Milestones

Within each program area, there are a few milestones that share common research topics. Two key research topics in particular are connected to multiple milestones: commercial CCHP and fuel flexibility.

Commercial CCHP RD&D

Cooling is a significant contributor to California's electricity load. CCHP is an effective and efficient way to utilize waste heat to drive a chiller. Two milestones address the need for CCHP RD&D: Effective *Building-Scale Integration of Thermally-Driven Chiller CCHP System Demonstrated* and *Cost-Competitive Thermally-Driven Chiller for CCHP Applications Demonstrated*.

Fuel Flexibility RD&D

To meet California's goals of reducing GHG emissions, fuel flexibility is an important criterion for power generation. Two milestones emphasize the need for fuel-flexible generation RD&D: *Fuel Flexibility Range for Key DG Technologies Established* and *Fuel-Flexible CHP Systems Powered by Key DG Technologies Demonstrated*. Fuel flexibility is intended to address a broad spectrum of renewable fuels, biofuels, digester gas, synthetic fuels and oxyfuel combustion. Increased fuel flexibility of DG technologies will facilitate achieving California policy goals around renewable portfolio standards and assist in reducing green house gas emissions.

Supporting these two RD&D areas will make a significant contribution to achieving state policy goals, such as AB 32 and the 33% RPS.

3.0 Implementation Plan

Generally, a research program must repeat three distinct steps as it implements its roadmap, which is presented in Figure 8 below.

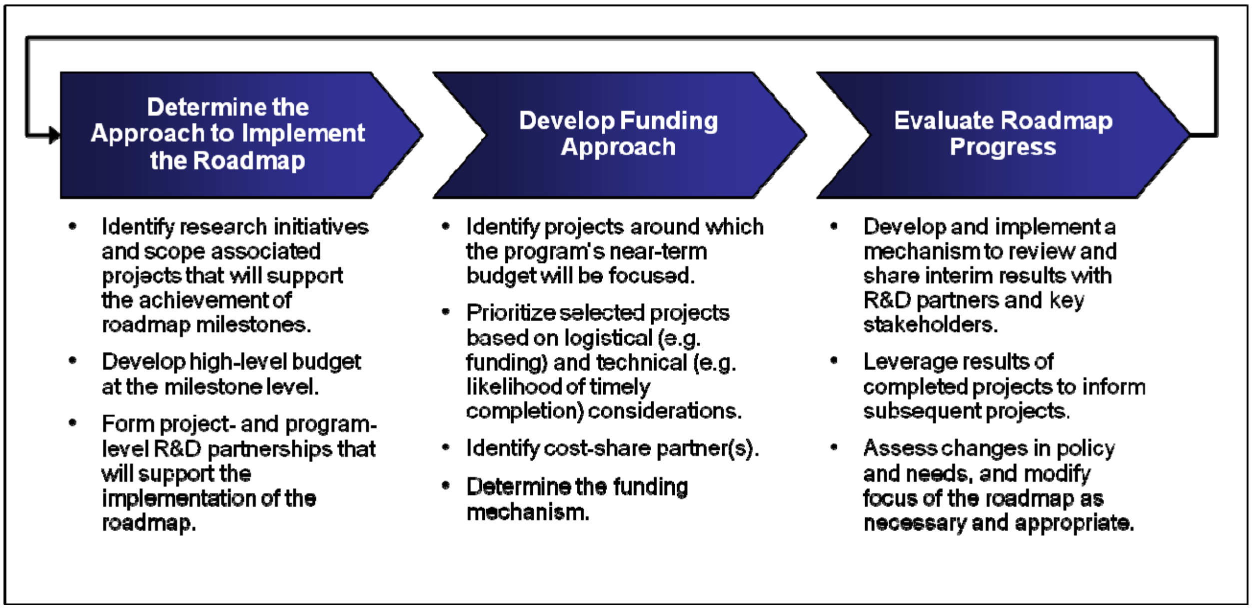

Figure 8. Generic Roadmap Implementation Process
Source: *Navigant Consulting, Inc.*

However, the roadmap implementation process for PIER Advanced Generation must be refined and integrated with the existing process with which PIER manages its RD&D portfolio. The following sections in this chapter will discuss details of this implementation process.

3.1. Roadmap Implementation Process

The roadmap implementation process for PIER Advanced Generation consists of four steps:

1. **Determining the approach to implement the roadmap:** First, PIER Advanced Generation will develop a general approach through which it implements the roadmap. This involves identification of research initiatives that will support the achievement of multiple roadmap milestones, development of a high-level, long-term budget plan at the milestone level, and establishing support mechanism for roadmap implementation by forming project- and program-level RD&D partnerships.
2. **Prioritize near-term goals in conjunction with the annual Work Plan:** Once the research initiatives are identified for all roadmap milestones, PIER Advanced Generation will then choose higher priority research initiatives that should be addressed with the upcoming FY budget. This determination will be based on the progress toward relevant policy goals at the time of deliberation, number of milestones to which a

research initiative is applicable, timing, and partnership opportunities within PIER. As appropriate, research initiatives should be enhanced and refined to better cater to the near-term RD&D needs.

3. **Develop and release solicitation:** PIER Advanced Generation will develop grant solicitation based on the research initiatives that were identified during the previous stage of roadmap implementation. PIER Advanced Generation will also identify cost-share partners as appropriate, based on the strategic objectives, the anticipated size and the desired timeframe of resulting RD&D projects. Responses to the solicitation will be reviewed, selected and prioritized based on logistical and technical considerations, including but not limited to funding availability and likelihood of timely completion. Once the winning proposals are chosen, PIER Advanced Generation will work with the contractors to finalize the scope of the project.
4. **Evaluate roadmap progress:** After it has accrued sufficient results (final, interim, or both) from its RD&D projects, PIER Advanced Generation will then evaluate its progress in implementing the roadmap and achievement of milestones. The project results will be reviewed and shared with internal and external stakeholders, including relevant PIER and Commission staff, program advisory committee and other RD&D partners. At this stage, PIER Advanced Generation will also assess any changes in policy and market needs that may influence its RD&D priorities and objectives. At the end of the last step, PIER Advanced Generation will have sufficient information to refine or modify the focus of the roadmap as necessary and appropriate. This will include modification milestones and identification of new milestones to achieve policy objectives and market needs in California.

Figure 9 summarizes the four stages of Advanced Generation roadmap implementation process.

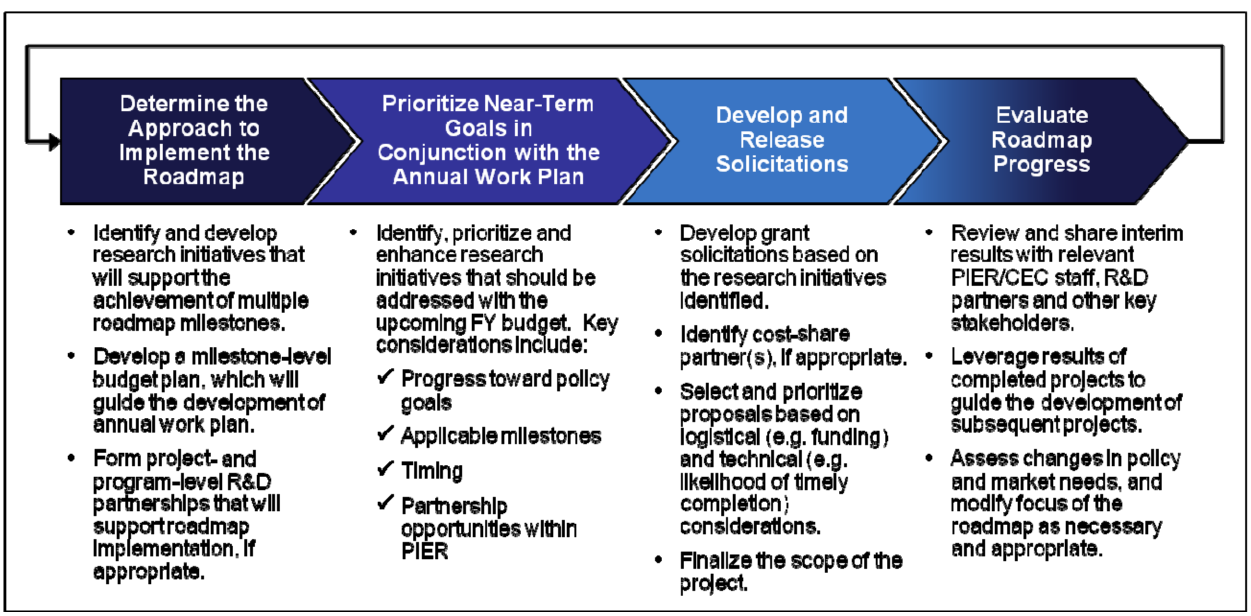

Figure 9. Roadmap Implementation Process for PIER Advanced Generation

Source: *Navigant Consulting, Inc.*

To best align its RD&D portfolio with the rapidly changing industry landscape, PIER Advanced Generation will first conduct an assessment of the relevant market, regulatory and economic barriers in California to aggressive adoption of advanced generation technologies as it prepares to implement the Roadmap. This preparatory step will be essential in developing and prioritizing appropriate near-term research initiatives in order to ensure they have maximum benefit.

3.2. Sequences of Research Initiatives

The PIER Advanced Generation Roadmap is intended to support development of technology through required technology maturation stages: Research & Development, which involves paper studies, component and primary technology development, materials research and proof-of-concept design and development; Demonstration, which involves demonstration of technical and economic viability of the technology, pilot scale and early field testing; Market Entry, which involves adoption of the technology by early movers and niche market; and full-scale Market Penetration as result of technical and commercial viability. Figure 10 presents typical technology maturation stages.

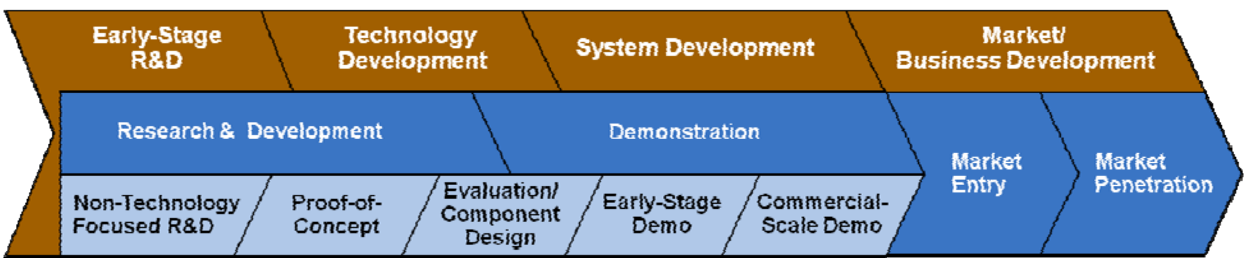

Figure 10. Typical Technology Maturation Stages
Source: *Navigant Consulting, Inc.*

Although there may be feedback to earlier stages, generally, these stages must occur in sequence, and individual stages should not be skipped in an attempt to accelerate the process.

3.2.1. RD&D Stages for Advanced Generation Roadmap Implementation

PIER Advanced Generation's charter is to focus its resources on technology-focused RD&D, mainly through its design, development and demonstration phases (see Figure 11).

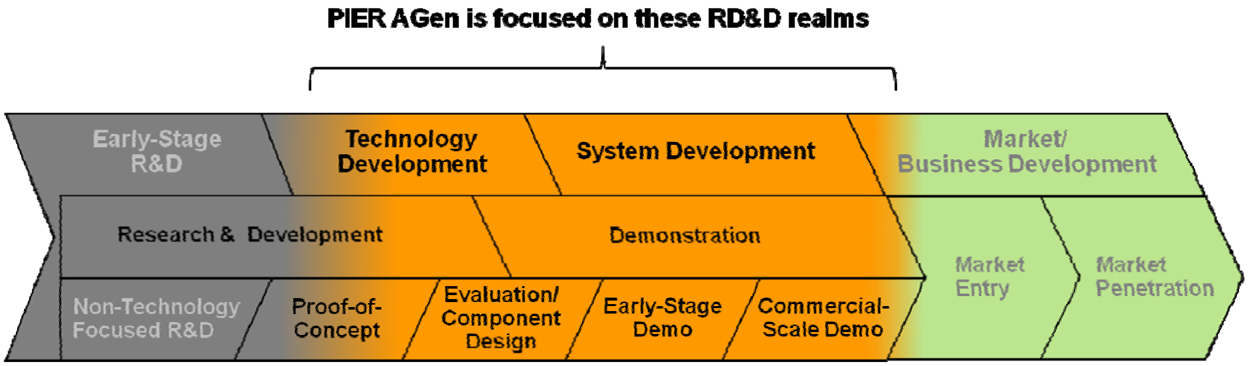

Figure 11. Focus of PIER Advanced Generation through the Technology Maturation Stages
Source: *Navigant Consulting, Inc.*

Given the focus of PIER Advanced Generation, three types of RD&D activities emerge for PIER Advanced Generation based on the technology maturation stages: Evaluation and Component Design; System Design/Early-Stage Demonstration; and Commercial-Scale Demonstration[2].

1. **Evaluation and Component Design:** The goal of this phase will be to develop basic components required for the target technology to achieve the level of performance that is attractive to the market. The focus of the RD&D effort during this phase will be to define desired system, and identify/resolve technical issues to achieve desired performance. Although potential activities for this phase may include evaluation of technology gap or market needs, PIER Advanced Generation will focus its resources for this phase on component technology development and refinement.
2. **System Design and Early-Stage Demonstration:** In addition to establishing technical viability of the target technology, the RD&D effort in this phase will improve the system performance of the technology (including cost performance) to match the industry needs. Necessary improvements for wide-scale market adoption will be determined and addressed. PIER Advanced Generation will develop initial system prototypes to demonstrate basic functionality, establish target cost and performance goals, and demonstrate feasibility of achieving the said goals.
3. **Commercial-Scale Demonstration:** RD&D effort in this phase will demonstrate a commercially viable application of the target technology that meets specific technical and economic goals. The goal of this phase is to credibly demonstrate and communicate to the industry that the target technology has viable economics and an acceptable level of technical uncertainties. The technology will be ready for transfer to commercial applications.

[2] Note that PIER Advanced Generation could leverage activities with PIER's Energy Innovations Small Grants Program to support proof-of-concept stage projects.

Figure 12 presents these three stages for Advanced Generation Roadmap implementation.

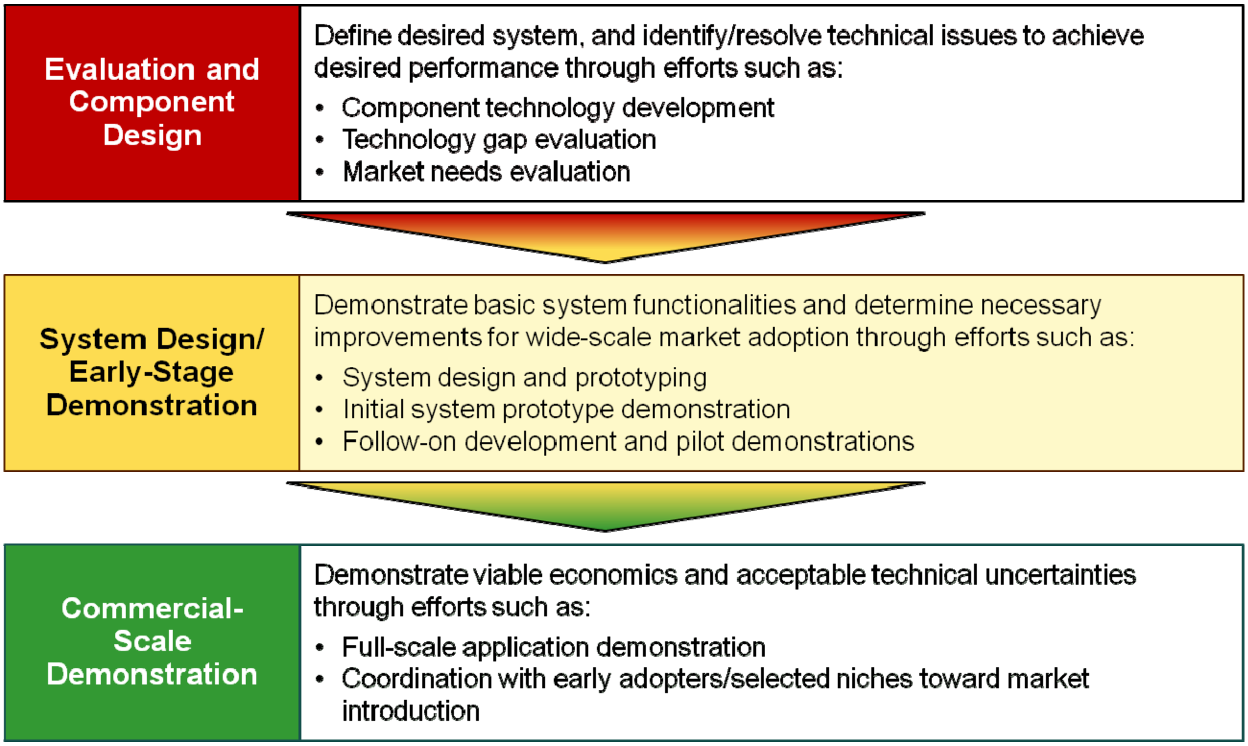

Figure 12. Three Stages for Advanced Generation Roadmap Implementation

Source: *Navigant Consulting, Inc.*

3.2.2. Representative Sequences of Research Initiatives

Based on the three stages for Advanced Generation Roadmap implementation, PIER Advanced Generation is developing sequences of research initiatives to achieve each of the roadmap milestones. Figure 13 and Figure 14 present the sequence of research initiatives for fuel-flexibility RD&D and commercial CCHP RD&D, respectively.

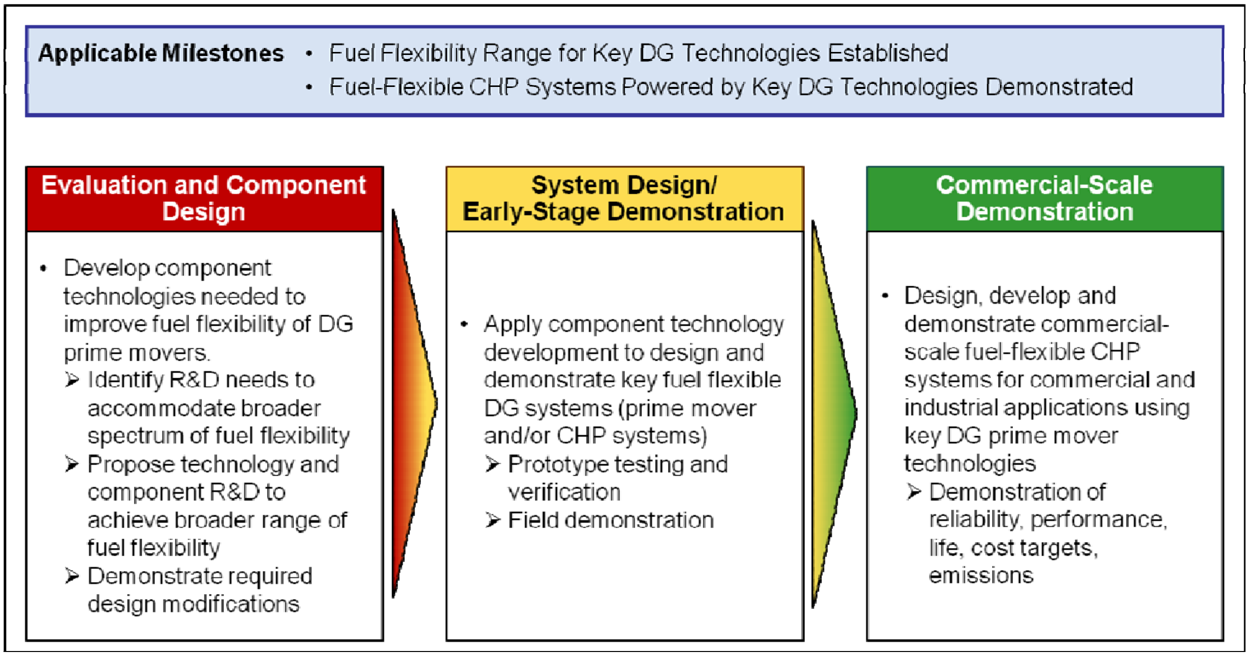

Figure 13. Sequence of Research Initiatives for Fuel Flexibility RD&D

Source: *Navigant Consulting, Inc.*

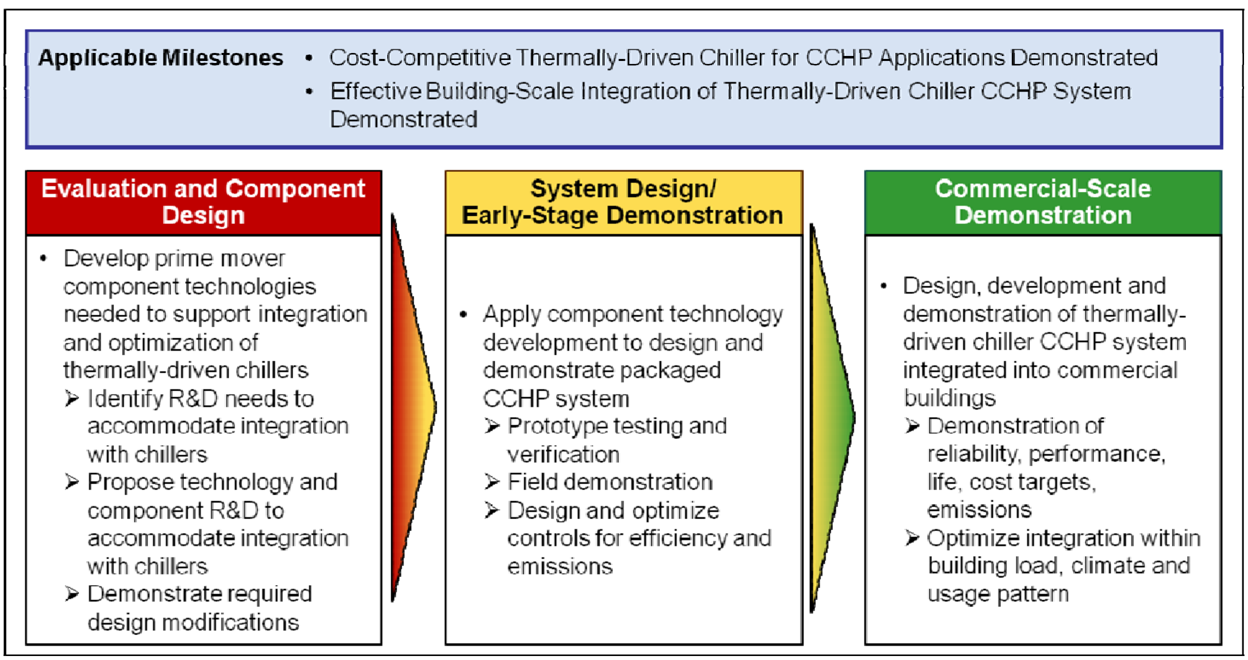

Figure 14. Sequence of Research Initiatives for Commercial CCHP RD&D

Source: *Navigant Consulting, Inc.*

3.3. Draft Budget Plan

PIER Advanced Generation has developed a draft budget plan at the milestone level based on the anticipated magnitude of RD&D investment efforts required to achieve a roadmap milestone, as well as their level of importance to the state policy goals. In developing the draft budget plan, PIER Advanced Generation first assigned ranges of total RD&D funding required to achieve the milestone: $5 million to $10 million; $10 million to $25 million; and $25 million to $50 million, depending on the degree of complexity and the perceived technical issues and risks to be addressed. A RD&D budget for the PIER Advanced Generation Program was then estimated based on the relative importance of each milestone to the state energy goals. The estimate for the PIER Advanced Generation budget assumes that PIER Advanced Generation will contribute between 10 to 40% of the total estimated budget for RD&D depending on the policy linkage. Table 2 presents the draft budget plan. This draft budget plan was reviewed with technical reviewers representing various stakeholders during the roadmap development process. These reviewers provided input regarding the budget requirements and the draft budget was adjusted based on this input.

Table 2. PIER Advanced Generation Draft Budget Plan by Milestones

Program Areas	Top-Priority Milestones	Relevant Policy Goals[3]	Total Estimated Budget ($ million)	Estimated Advanced Generation Budget ($ million)	Total Program Area Budget ($ million)
Commercial CHP/CCHP	Cost-Competitive Absorption Chiller for CCHP Applications Demonstrated	CHP, AB 32, SB 1250	10 – 25	4 – 8	8 – 16
	Effective Building-Scale Integration of Absorption Chiller CCHP System Demonstrated	CHP, AB 32, SB 1250	10 – 25	4 – 8	
Industrial Cogeneration	Impact of Alternative Fuels Use on CHP System Determined	CHP, AB 32, SB 1250	5 – 10	2 – 4	12 – 19
	Standardized, Fully-Integrated CHP Systems Demonstrated for Key Applications	CHP, AB 32, SB 1250	25 – 50	10 – 15	
Advanced Gas Turbine Cycles	Economic Viability of Efficiency Technology Options for Retrofit Applications Determined	AB 32, SB 1250	10 – 25	2 – 3	10 – 18
	Hybrid Renewable Cycle Systems Integration with Combined Cycle Plants Demonstrated	RPS, AB 32, SB 1250	25 – 50	5 – 10	
	Fuel Cell-Hybrid Combined Cycle System Demonstrated	RPS, AB 32, SB 1250	10 – 25	3 – 5	
Cross-Cutting	Fuel Flexibility Range for Key DG Technologies Established	CHP, AB 32, SB 1250	5 – 10	2 – 4	8 – 15
	Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated	AB 32, SB 1250	10 – 25	2 – 3	
	Fuel-Flexible Commercial/Industrial CHP Systems Powered by Key DG Technologies Demonstrated	CHP, AB 32, SB 1250	10 – 25	4 – 8	

Source: *Navigant Consulting, Inc.*

[3] "AB 32" indicates a tie to Assembly Bill 32, "RPS" indicates a tie to the 33% RPS from Governor's Executive Order S-3-05, "SB 1250" indicates a tie to Senate Bill 1250, and "CHP" indicates a tie to the Air Resources Board's (ARB) AB 32 Scoping Plan goal of installing 4,000 MW of CHP by 2020.

3.4. Partnership Strategy and Recommendations

Successful implementation of a research roadmap requires strong RD&D partnerships and networks. There are two types of partnerships that are desired by the Advanced Generation Program: project-level RD&D partners, and program-level advisors/reviewers.

Project-level partners are entities that will work in tandem with PIER Advanced Generation to execute, or support completing, RD&D projects. Potential contributions include providing technical expertise, providing venues for demonstration, co-funding and co-management of projects to ensure successful completion of projects, or any combination thereof. These partners may include technology providers (such as equipment manufacturers and engineering firms), local governments, research universities, national labs, other state and federal technology research organizations and other technical experts.

Program-level advisors/reviewers are expected to provide expert insight, industry perspective and constructive guidance which will help PIER Advanced Generation maintain its alignment with the program vision as well as the surrounding policy and market landscapes. Once the roadmap is finalized, PIER Advanced Generation will convene a Program Advisory Committee (PAC) as a channel through which PIER Advanced Generation can engage its expert advisors. Potential roles of the PAC are summarized in Table 3.

Table 3. Potential Roles of PIER Advanced Generation Program Advisory Committee

Program Planning, Development and Review	Extended Enterprise and Networking
• Participate in developing new ideas and initial scoping of new concepts • Enhance implemented projects - Provide general direction and feedback - Identify potential linkages with other activities (internal and external) • Provide ongoing critical, constructive review of the program • Participate in program/roadmap reviews	• Provide information and ideas for new collaboration opportunities • Provide another forum for California industry stakeholders to share information with one another • Provide a virtual extension of the program resources by tapping the committee's expertise and network • Increase awareness of program through committee members' networks and contacts

Source: *Navigant Consulting, Inc.*

For the Advanced Generation PAC to successfully support PIER Advanced Generation in implementing its roadmap and continuously refining its focus, PAC members must represent a diverse array of backgrounds and perspectives. To the extent possible, PIER Advanced Generation will ensure that its PAC will include members who represent the Federal perspective (i.e. Department of Energy), state government perspective (e.g., California Public Utilities Commission and ARB), utility/grid-side perspective (e.g., California utilities and California Independent System Operator), and technology implementation perspectives (e.g., manufacturers and independent power producers).

3.5. Roadmap Progress Evaluation and Revision Process

Knowledge gained through the series of RD&D projects implemented based on the roadmap must be leveraged to guide the development of subsequent solicitations and RD&D projects. The research roadmap is a dynamic document that will require regular refinement throughout its implementation process. As Figure 15 illustrates, PIER Advanced Generation will evaluate the progress of its Roadmap implementation once it accrues a critical mass of project outcomes from the first round of solicitations.

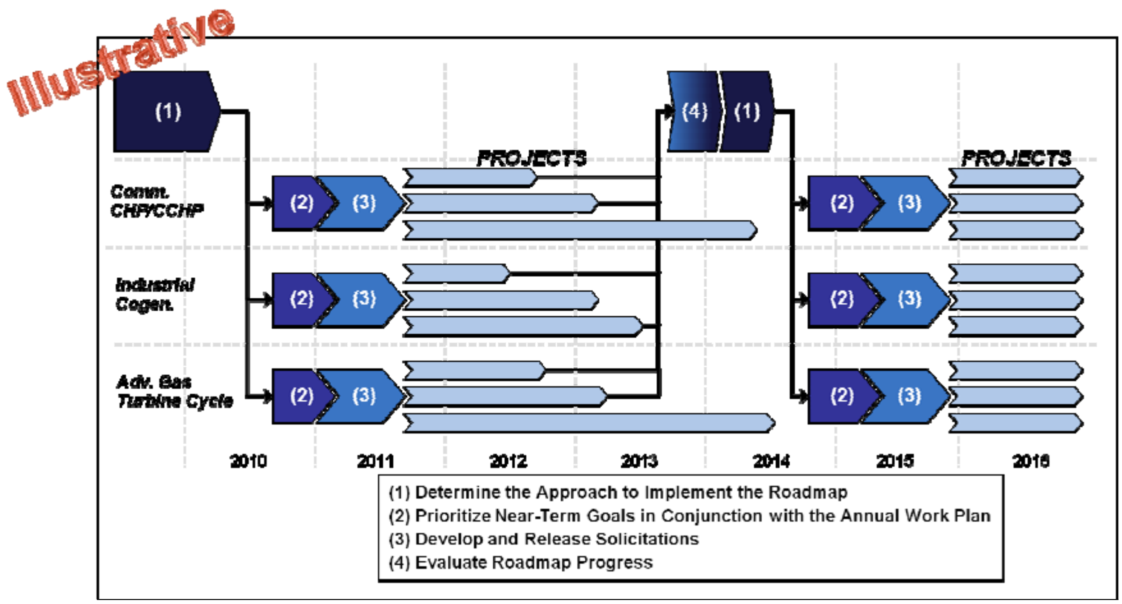

Figure 15. Illustrative Roadmap Implementation Timeline

Source: *Navigant Consulting, Inc.*

Evaluation of roadmap progress involves critical review of available results from ongoing and completed RD&D projects with relevant stakeholders, including PIER/Energy Commission staff, Advanced Generation PAC, project-level R&D partners and other key stakeholders. As the team of stakeholders reviews the latest results from the implementation of the roadmap, PIER Advanced Generation should also assess and evaluate relevant changes in policy and market needs that may influence the near-term priorities for PIER Advanced Generation. At the end of this evaluation, PIER Advanced Generation will not only be able to leverage results of its current RD&D portfolio to guide the development of subsequent projects, it will also have clear direction on how to calibrate and refine the focus of its roadmap as necessary and appropriate.

As discussed in Section 3.1, PIER Advanced Generation will perform an initial analysis of market, regulatory and economic barriers in California associated with adoption of advanced generation technologies before the Roadmap is implemented to ensure maximum benefit.

4.0 Glossary

AB 32	Assembly Bill 32
ARB	California Air Resources Board
CA	California
CCHP	combined cooling heating and power
CCS	carbon capture and sequestration
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
DER	distributed energy resources
DG	distributed generation
DOE	Department of Energy
DR	demand response
Energy Commission	California Energy Commission
GHG	greenhouse gas
GT	gas turbine
HVAC	heating, ventilation and air conditioning
IC	internal combustion
IGSC	integrated gasification simple cycle
IEPR	*Integrated Energy Policy Report*
IOU	investor-owned utility
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
MW	megawatt
MWh	megawatt-hour
NG	natural gas

NOx	nitrous oxides
NSR	new source review
OTC	once-through cooling
PAC	Program Advisory Committee
PIER	Public Interest Energy Research
Advanced Generation	Public Interest Energy Research Advanced Generation Program
PV	photovoltaic
R&D	research and development
RD&D	research, development, and demonstration
RPS	Renewables Portfolio Standard
Rule 21	California Electric Rule 21–Generating Facility Interconnections
SB 1250	Senate Bill 1250
SB 1368	Senate Bill 1368
US	United States
VOC	volatile organic compound
WESTCARB	West Coast Regional Carbon Sequestration Partnership

5.0 Appendix

5.1. Detailed Roadmap Development Process

The development of the roadmap followed the steps outlined in Figure 16.

Figure 16. Roadmap Development Process

Source: *Navigant Consulting, Inc.*

The roadmapping process began with background research into 26 advanced generation focus technologies. These technologies include microturbines, fuel cells, thermally-driven chillers, and hybrid renewable cycles.[4]

The research captured the current status of each technology, including costs, efficiencies, emissions, existing R&D, and market barriers. These profiles were included in the PIER Advanced Generation Roadmap Background Paper[5] and presented at the 2009 IEPR Staff Workshop on advanced generation technologies on August 10, 2009[6]. After each technology was profiled, a gap analysis was conducted to determine target RD&D areas where PIER Advanced Generation could make a significant contribution toward removing market barriers and commercializing advanced generation technologies. Many of the gaps fell within the three program areas of PIER Advanced Generation: commercial CHP/CCHP, industrial cogeneration, and advanced gas turbine cycles.

5.1.1. Milestone Selection and Prioritization

Preliminary program milestones were developed for each of the R&D gaps identified from the technology profiling, and cover a wide range of technologies and other R&D issues. The milestones were developed to lead to achievement of PIER Advanced Generation's program vision, and will assist PIER Advanced Generation in demonstrating that progress towards this goal has been made. Thirty-one (31) preliminary milestones were identified. The preliminary milestones are described below, by program area.

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[4] See Section 4.2 for additional details on these 26 technologies.

[5] Contreras, Jose Luis, David Walls, Erin Palermo, David Feliciano (Navigant Consulting, Inc.). *Advanced Generation Roadmap Background Paper, 2009*. California Energy Commission, PIER Program. CEC-500-2009-086.

[6] Refer to the records from the *Staff Workshop on Advanced Generation* (available at http://www.energy.ca.gov/2009_energypolicy/notices/2009-08-10_workshop.html) and articles [4] and [15] published in the California Energy Markets, No. 1041 for additional details about the IEPR proceedings.

Commercial CHP/CCHP Milestones

C1) **Effective Incentive Options Established for Commercial CHP:** Determine required incentive levels and options to reach target penetration of commercial CHP systems. Identify key economic and operational barriers for adoption and potential approaches to overcome these barriers through an effective incentive mechanism.

C2) **Viability of DG Technologies for Commercial CHP Application Determined:** Determine the viability of different DG technology for commercial-scale CHP applications in California market. Evaluate the costs and benefits of standardized system design and adoption practices that are tailored for specific applications (e.g., food service facility, office buildings and hospitals), and optimized for the California market. Key considerations include the impact of higher ambient temperature due to the proximity of the thermal output to the gen set, inherent capacity limitations associated with DG technology, outlook for performance improvement of DG technologies, and California-specific climate and use patterns.

C3) **Viability of DG Technologies for Hybrid-Fuel Cell Applications Determined:** Determine the viability of different DG technologies as a prime mover option for commercial-scale hybrid fuel cell system applications in California market. Evaluate technical feasibility and commercial potential of different DG technologies in the context of California's unique market, regulatory and environmental conditions. Key considerations include pollutant emissions performance of DG technology (may adversely affect fuel cell performance), compatibility with performance parameters of fuel cell technologies (e.g., pressure ratios and mass flows), outlook for technology advancements of DG technologies to improve compatibility with fuel cells.

C4) **Fuel-Flexible Commercial CHP systems Powered by Key DG Technologies Demonstrated:** Demonstrate a fuel-flexible commercial CHP system powered by key DG technologies (e.g., fuel cells, microturbine, Stirling engine, gas turbine, reciprocating engine and gas turbines), without significant degradation of energy and environmental performance. The demonstration should address current technology limitations, including high cost and minimum performance level over a range of ambient conditions.

C5) **Cost-Competitive Fuel Cell-Integrated CHP System Developed:** Improve the energy and environmental performance of fuel-cell-integrated CHP systems to increase its financial appeal for commercial application in California. Approaches to reduce costs of fuel cell-integrated CHP system include adjusting thermal/electric ratios, and standardized packaged FC-integrated CHP design for specific commercial applications.

C6) **Cost-Competitive Stirling Engines CHP Applications Demonstrated:** Improve the energy and environmental performance of Stirling engines to increase its financial appeal for commercial CHP application in California. Approaches to reduce costs of Stirling engine technology include developing standardized packaged Stirling engine CHP technologies for specific commercial applications, creating incentive structures to support Stirling and demonstrating the reliability of a Stirling engine in CHP applications.

C7) **Cost-Competitive Microturbine CHP Applications Demonstrated:** Improve the energy and environmental performance of microturbines to increase its financial appeal for commercial CHP application in California. Approaches to reduce costs of microturbine technology include developing standardized packaged microturbine CHP technologies for specific commercial applications, and addressing loss of power output and efficiency at higher temperatures and elevation through cycle enhancements.

C8) **Performance Characteristics of Stirling Engine Systems Established:** Assess and document performance characteristics of Stirling engine technology for commercial-scale CHP application in California. Key considerations include variance in performance parameters based on engine design, size and ambient operating conditions.

C9) **Cost-Competitive Absorption Chiller for CCHP Applications Demonstrated:** Improve the energy and environmental performance of absorption chillers to increase its appeal for commercial CCHP application in California. Approaches to reduce costs of absorption chiller technology include creating incentive structures to support absorption chiller CCHP systems, improving chiller efficiencies when paired with CHP systems, and optimizing the chiller design to typical ambient operating conditions in California.

C10) **Effective Building-Scale Integration of Absorption Chiller CCHP System Demonstrated:** Demonstrate a commercial building-scale absorption chiller CCHP system. This Demonstration will address current technology limitations, including high cost, minimum performance level in a range of ambient conditions, and integration with HVAC systems commonly used in commercial buildings in California.

C11) **Viability of Absorption Chillers for CCHP Applications Established:** Determine the viability of absorption chiller technology for commercial-scale CCHP applications in California market is demonstrated. Technical feasibility and commercial potential of CCHP with absorption chillers is understood in the context of California's unique market, regulatory and environmental conditions. Key considerations include integration with existing HVAC systems commonly used in California as well as California-specific climate and use patterns.

Industrial Cogeneration Milestones

I1) **Effective Incentive Options Established for Industrial CHP**: Determine required incentive levels and options to reach target penetration of industrial CHP systems. Identify key economic and operational barriers for adoption and potential approaches to overcome these barriers through effectively incentive mechanism.

I2) **Efficiency Improvement Potential of Thermal Energy Recovery Technologies for Industrial CHP Applications Demonstrated**: Improve the energy and environmental performance of industrial CHP system for application in California's market through integration of thermal energy recovery system. Demonstrate the potential of the heat recovery technology to reduce cost and increase value of industrial CHP system.

I3) **Fuel-Flexible Industrial CHP Systems Powered by Key DG Technology Demonstrated**: Demonstrate a fuel-flexible industrial CHP system powered by key DG technologies without significant degradation of energy and environmental performance. The demonstration should address current technology limitations, including high cost and minimum performance level over a range of ambient conditions.

I4) **Low-Emission Prime Mover Options for Industrial CHP Applications Demonstrated**: Demonstrate low-emission prime mover options for industrial CHP application in California. Given California's aggressive emissions requirements, the demonstration will focus on prime movers with low nitrogen oxides (NOx) emissions with near-term feasibility for adoption.

I5) **Emission Control Approaches For Varying Load Conditions Established**: Develop criteria pollutant control technologies that will reduce emissions at various load conditions typical of California industrial sites. Development should focus on controls to address higher NOx emissions at higher loads and higher carbon monoxide (CO) and volatile organic compounds (VOC) emissions at lower loads to meet California's emissions requirements.

I6) **Implications of Alternative Fuels Use on Industrial CHP System Design Determined**: Assess the implications of alternative fuel use to operate industrial CHP systems. Key considerations include modifications to prime movers, fuel handling and treatment, and fuel storage.

I7) **Standardized, Fully-Integrated Industrial CHP Systems Demonstrated for Key Applications**: Demonstrate standardized, fully-integrated industrial CHP for applications in California. Key considerations include optimization to California's climate, key applications and associated usage patterns, cost reduction and ease of integration into existing facilities. This research should focus on key applications that are most prevalent in California's industry sector.

I8) **Cost-Competitive Industrial CHP System Integrated with Energy Storage Demonstrated**: Improve the energy performance of industrial CHP system to increase its financial appeal through integration with energy storage. Demonstrate the viability of integration both electric and thermal storage technologies aimed at reducing costs of total CHP system to increase value proposition to end-users.

I9) **Gross GHG and Criteria Pollutant Impact of Industrial CHP System Determined**: Assess and evaluate gross GHG and criteria pollutant emissions impacts of industrial CHP systems. The Clean Air Act's New Source Review (NSR) is a permitting barrier to installation of CHP systems. NSR requires large, stationary sources of air pollutants to install state-of-the-art pollution control equipment at the time of construction or whenever major modifications are made that can increase net emissions. CHP systems increase the emissions of a facility but significantly reduce total gross emissions because of their high efficiencies. Evaluate total GHG impact as a result of new industrial CHP, taking into consideration California's emissions regulations.

I10) **Optimal Site Profile for Industrial CHP Determined**: Characterize the steam/heat loads and electricity generating potential of California industrial sites that are potentially good candidates for CHP systems, both in terms of on-site operations and electricity export applications. This market information will inform the technology development of not only traditional CHP systems for on-site applications, but also CHP systems that can export excess electricity to the grid while provide the industrial site with the necessary heat and steam load.

Advanced Gas Turbine Cycles Milestones

A1) **Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated**: Analyze the costs and benefits of various retrofit technologies for advanced gas turbine cycle (e.g., cooling technologies, recuperators, recuperated gas turbines and heat recovery) in California. Evaluate and document the efficiency potential of these retrofit options, and assess its economic viability given their high capital cost.

A2) **Cost-Competitive Advanced Gas Turbine Cycle Systems Developed for California**: Support research that will reduce the cost of advanced gas turbine system designed for California-specific conditions. Key component that drives the cost of advanced gas turbine cycle systems (e.g., recuperated gas turbines, intercooled recuperated cycles and gas turbine cycles with heat recovery) is heat exchanger, which could be optimized for operating conditions in California.

A3) **Performance and Hardware Limitations of Fog Intercooling Determined**: Analyze performance limitations, and infrastructure implications (e.g., maintenance and lifecycle impacts) of fog intercooling. Fog intercooling shows the greatest promise of all inlet cooling technologies viable for California, but its risks associated with reliability, hardware corrosion, and pitting must be evaluated

A4) **Fuel-Flexible Advanced Simple Cycle for Peaking Application Demonstrated**: Demonstrate the technical viability of fuel-flexible advanced simple cycle for peaking.

A5) **Cost-Competitive Approaches to Mitigate Intermittency of Renewables Resources with Hybrid Renewable Cycle Established**: Analyze approaches to mitigate intermittency issues of renewable resources for hybrid cycle application. This research should leverage existing research on concentrated solar power, and should serve as a guiding work for a larger-scale demonstration of hybrid renewable cycle systems.

A6) **Hybrid Renewable Cycle Systems Integration with Combined Cycle Plants Demonstrated**: Demonstrate hybrid renewable cycle systems integrated with combined cycle plant. This research may entail small-scale demonstration first to understand performance characteristics. This research will demonstrate the viability of integrating renewable resources into combined cycle plant operation. Given the abundance of solar resources in California, this research should focus on increasing the amount of solar share in hybrid cycle.

A7) **Economic Viability of Integrating IGSC with Power Generation Technologies in California Determined**: Analyze and evaluate potential efficiency improvements from integration of integrated gasification simple cycle (IGSC) with the latest power generation technologies, including gas turbines (GT) and internal combustion (IC) engines.

A8) **Cost-Competitive IGSC Systems to Augment IC and GT Plants Demonstrated in Retrofit Applications**: Improve the energy and environmental performance of traditional IC and GT plants through integration of IGSC system. Evaluate the costs and benefits of retrofit approaches for IGSC systems.

Cross-Cutting Milestones

X1) **Appropriate Range of Fuel Flexibility Established for Commercial/Industrial CHP Applications**: Assess and determine the appropriate range of fuel flexibility for commercial and industrial CHP/CCHP systems in California. Key considerations include the characteristics of most promising technology options for prime movers, availability of feedstocks for alternative fuels and availability of fuel distribution infrastructure. Evaluate different alternative fuel options for their technical and economic potential in commercial /industrial CHP application.

X2) **Cost and Performance Improvement Targets for Heat Recovery Technologies Demonstrated for Industrial CHP/Power Generation Applications**: Assess the current state of heat recovery technology options for industrial CHP and power generation applications. Determine and demonstrate cost and performance improvement targets for key heat recovery technologies especially relevant for California. A key parallel to be considered is the economics and operation of renewable generation; economics and operation of heat recovery technologies are similar to renewables projects, in that they require large up-front investment and minimal fuel cost.

Each of the preliminary milestones was scored based on two criteria: level of importance and feasibility. Level of importance is a composite score, considering the significance of a milestone to achievement of the state policy goals, and the need for PIER Advanced Generation funding. The scoring rubric for the level of importance criteria is shown in Figure 17 and Figure 18.

Policy Impact Score				
1	2	3	4	5
R&D will have minimal impact to the achievement of CA policy goals	R&D will enable other clean generation techs to achieve CA policy goals	R&D will encourage adoption of clean generation tech to achieve CA policy goals	R&D will improve the performance of clean generation tech to achieve CA policy goals	R&D will significantly improve the performance of clean generation tech in achieving CA policy goals
Low		Medium		High

Figure 17. Policy Impact Scoring Rubric

Source: *Navigant Consulting, Inc.*

Need for PIER AGen Funding Score				
1	2	3	4	5
No need; tremendous RD&D in this area already	Limited need; there are substantial RD&D efforts in this area already	Moderate need; no RD&D effort ongoing, but other entities may be better equipped to perform R&D	Large need; no RD&D efforts ongoing, with limited outlook for additional R&D.	Tremendous need; no outlook for significant RD&D in this area.
Low		Medium		High

Figure 18. Need for PIER Advanced Generation Funding Scoring Rubric

Source: *Navigant Consulting, Inc.*

The feasibility criteria is also a composite score, taking into account the opportunity for R&D partnership in achieving a milestone, as well as risks associated with technology adoption. The scoring scales for the feasibility criteria are shown in Figure 19 and Figure 20.

Partnership Opportunity Score				
1	2	3	4	5
Low strategic value in partnership, with limited availability of potential partners	Moderate strategic value in partnership, with limited availability of potential partners	Tremendous strategic value in partnership, but limited availability of potential partners	Tremendous strategic value in partnership, but moderate availability of potential partners	Tremendous strategic value in partnership, with high availability of potential partners
Low		Medium		High

Figure 19. Partnership Opportunity Scoring Scale

Source: *Navigant Consulting, Inc.*

Technology Risk Score				
1	2	3	4	5
Low likelihood that the technology will perform as desired	Moderate likelihood that technology will perform as desired	High technology likelihood, but low likelihood that market will adopt	High technology likelihood and moderate market	High likelihood that technology will perform and market will adopt
Low		Medium		High

Figure 20. Technology Risk Scoring Scale

Source: *Navigant Consulting, Inc.*

Once each of the 31 milestones was scored, they were ranked according to priority: low, medium, medium-high and high. The preliminary ranking of the 31 milestones is shown in Figure 21.

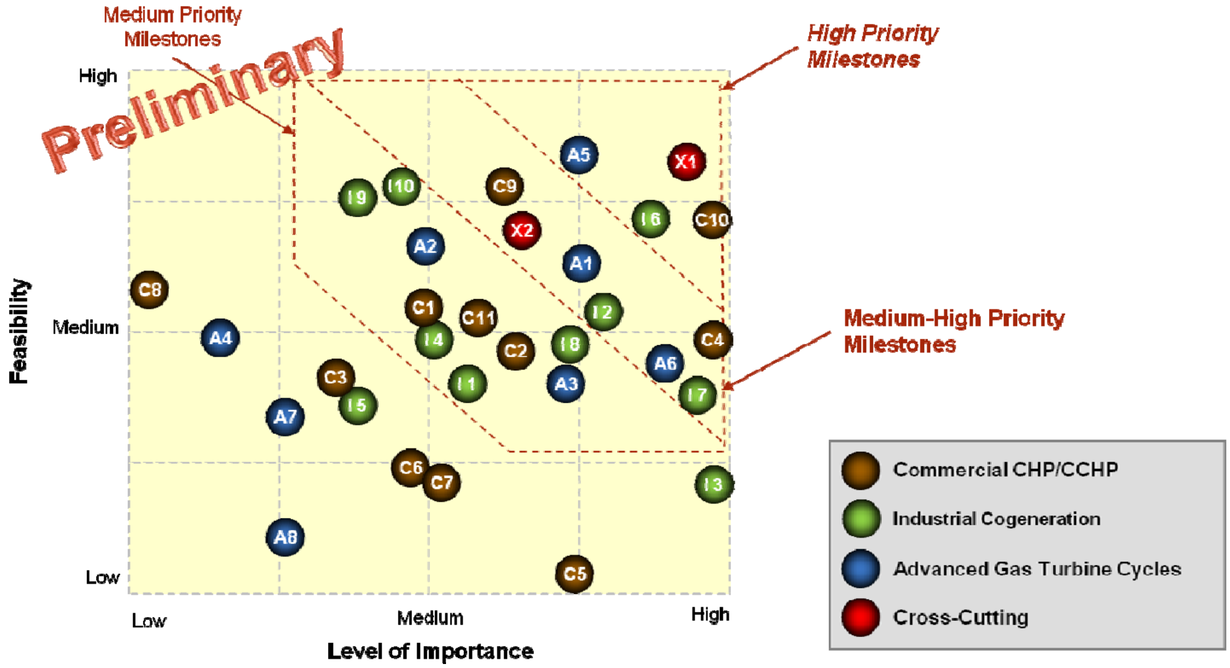

Figure 21. Preliminary Milestone Ranking

Source: *Navigant Consulting, Inc.*

The preliminary ranking identified eleven top priority milestones. Top priority milestones are those with medium-high or high priority rankings. The eleven top priority milestones were evenly distributed across the three program areas.

5.1.2. Technical Review Meeting

On September 3, 2009, a Roadmap Technical Review Meeting was conducted. This meeting was designed to solicit feedback from industry experts on the preliminary top priority milestones. Table 4 presents the technical experts who participated in the meeting.

Table 4. Participants of September 3, 2009 Technical Review Meeting

Organization Type	Name	Organization
DG/CHP	Gearoid Foley	Integrated CHP Systems Corp
	William Martini	Tecogen
	Robert Panora	Tecogen
Equipment Manufacturers	Wayne Bliesner	ADI Thermal Power Corp
	Jeff Stroh	Makel Engineering, Inc.
	Christopher Miller	General Electric Energy
	Matt Zedler	General Electric Energy
Law	Michael Nelson	McCarthy Law
National Lab	Tom Baginski	Lawrence Livermore National Lab
Non-Profit / Associations	Crystal Muhlenkamp	Conservation Strategy Group
	Susan Patterson	Gas Technology Institute
	John Pratapas	Gas Technology Institute
	Grant Vospher	Green Energy Systems
Government Agency	Kris Flaig	City of Los Angeles
	Keith Roderick	California Air Resources Board
	Curtis Seymour	California Public Utilities Commission
	Ihshan Yeh	City of Los Angeles
University	Richard Hack	UC Irvine
	Vince McDonell	UC Irvine
Utility	Manuel Alvarez	Southern California Edison
	Jacqueline Jones	Southern California Edison
Other	Keith Davidson	DE Solutions
	Rick Tidball	ICF International
	Kenneth Lee	Worley Parsons Group Inc
	Jared Moore	Worley Parsons Group Inc

The reviewers were presented with the eleven top priority milestones, as well as background information about the milestone selection process, and were then asked to score the milestones themselves. Six of the technical reviewers submitted scorecards with their ranking of the 31 program milestones, and their scores were compared to the preliminary rankings. Some reviewers suggested additional milestones, one of which was selected to send to the group of technical reviewers for additional scoring.

After compiling the results of the technical reviewers' feedback, the milestone rankings were updated. The revised ranking yielded eleven top priority milestones, shown in Table 5.

Table 5. Finalized Top Priority Milestones

Program Areas	Top-Priority Milestones	
	High Priority	**Medium-High Priority**
Commercial CHP/CCHP	• Effective Building-Scale Integration of Thermally-Driven Chiller CCHP System Demonstrated	• Cost-Competitive Thermally-Driven Chiller for CCHP Applications Demonstrated
Industrial Cogeneration	• Impact of Alternative Fuels Use on Industrial CHP Systems Determined	• Standardized, Fully-Integrated Industrial CHP Systems Demonstrated for Key Applications • Cost-Competitive Industrial CHP System Integrated with Energy Storage Demonstrated
Advanced Gas Turbine Cycles	None	• Cost-Competitive Efficiency Technology Options for Retrofit Applications Determined • Hybrid Renewable Cycle Systems Integration with Combined Cycle Plants Demonstrated • Fuel Cell-Hybrid Combined Cycle System Demonstrated
Cross-Cutting	• Fuel Flexibility Range for Key DG Technologies Established	• Cost and Performance Improvement Targets for Heat Recovery Technologies Demonstrated for Industrial CHP/Power Generation Applications • Fuel-Flexible Commercial/Industrial CHP Systems Powered by Key DG Technologies Demonstrated

Source: *Navigant Consulting, Inc.*

5.1.3. Roadmap Review Meeting

After finalizing the top priority milestones, each of the eleven milestones was placed on the PIER Advanced Generation roadmap (Figure 22).

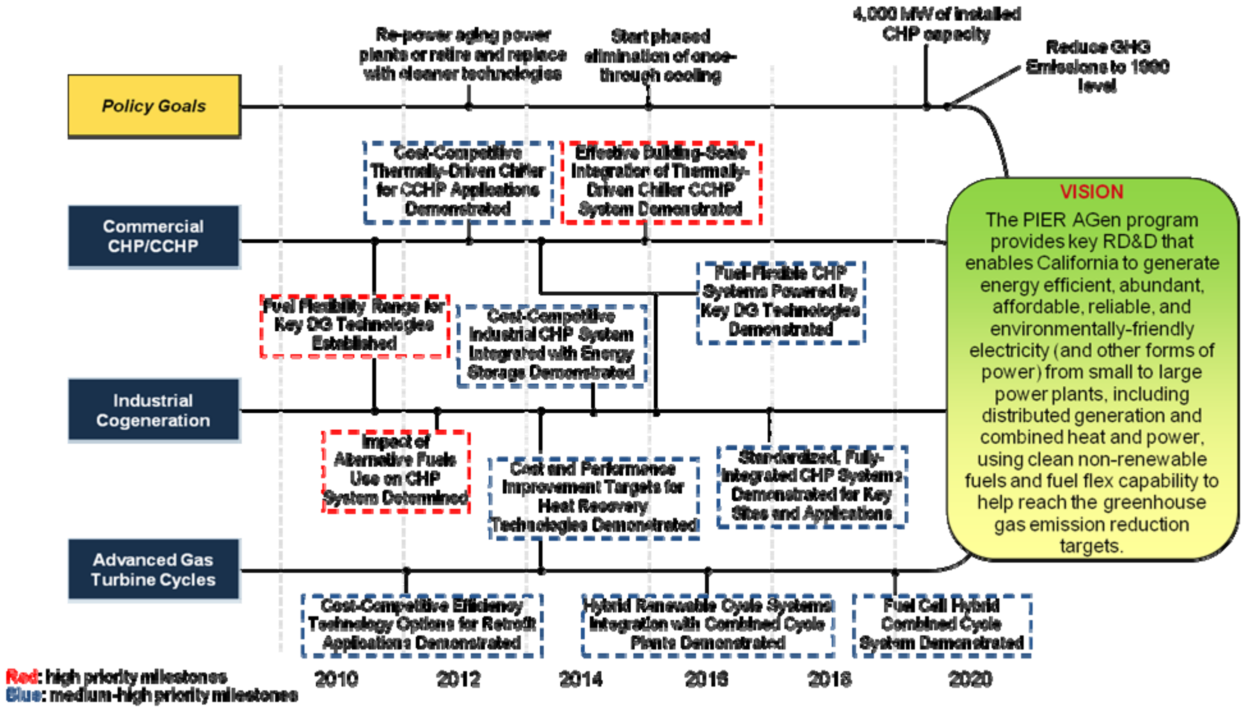

Figure 22. PIER Advanced Generation Draft Roadmap

Source: *Navigant Consulting, Inc.*

PIER Advanced Generation convened a Final Roadmap Review meeting on September 24, 2009 with its technical reviewers. Table 6 presents the technical experts who participated in the meeting.

Table 6. Participants of September 24, 2009 Roadmap Review Meeting

Organization Type	Name	Organization
Equipment Manufacturer	Jim Halloran	Caterpillar
	Steve Doyle	Clean Energy Systems
	Edward Lyford-Pike	Cummins, Inc
	Donald Kendrick	Lean Flame
	Neil Blythe	General Electric
	Dan Giordano	Sturman Industries
	Joe Vollmer	Sturman Industries
Equipment Supplier	Grant Vospher	Green Energy Systems
	James Zurlo	Dresser, Inc.
	Bill Clary	MIRATECH
National Lab	Patti Garland	Oak Ridge National Lab
Non-Profit / Associations	John Pratapas	Gas Technology Institute
	Richard Menar	Electric Power Research Institute
	Dale Grace	Electric Power Research Institute
	Joe Suchecki	Engine Manufacturers Association
Government Agency	Alfonso Baez	South Coast Air Quality Management District
	Howard Lange	South Coast Air Quality Management District
	Marshall Enderby	California Public Utilities Commission
University	Clifford Haefke	University of Illinois, Chicago
	Richard Hack	University of California, Irvine
	Ashok Rao	University of California, Irvine
	Gerardo Diaz	University of California, Merced
Utility	Joe McCawley	Southern California Edison
Others	Jerald Cole	Hydrogen Ventures
	Anna Shipley	Sentech
	Jonathan Woodside	Graduate Student
	Liz Richardson	American Electrical Testing Co.
	Kirk Woodside	N/A
	Nolan Sambrano	ADEPT Group, Inc
	Alex Spataru	ADEPT Group, Inc

The participants from this Roadmap Review meeting were invited to submit comments on the draft Final Roadmap Report. Their comments are summarized in Section 4.3.

A few of the technical reviewers expressed interest in being a member of the Advanced Generation Program Advisory Committee. These reviewers are listed below in Table 7.

Table 7. Prospective Program Advisory Committee Members

Organization Type	Name	Organization
Equipment Manufacturers / Suppliers	Donald Kendrick	Lean Flame
	Bill Clary	MIRATECH
	Joe Vollmer	Sturman Industries
Other	Jerald Cole	Hydrogen Ventures

5.2. PIER Advanced Generation Roadmap Background Paper - Summary

The Advanced Generation program is one of the key focus areas for the PIER Program. Over the last 10 years, PIER Advanced Generation has invested $102 million in advanced electricity generation, which is roughly 20 percent of its RD&D funding. Distributed generation and combined heat and power systems have been a key research focus area for the PIER Advanced Generation Program in the past. The program embarked on developing a roadmap and considering including larger scale advanced generation technologies in addition to its traditional focus on distributed generation technologies. Investing in advanced generation technology provides an opportunity for developing clean, reliable, affordable, secure, and sustainable power. A background paper, prepared as a part of the 2009 Integrated Energy Policy Report Staff Workshop on Advanced Generation Technology RD&D, examined the state and federal policy framework for advanced generation in California, assessed the current status of advanced generation technologies, and identified significant trends and issues as well as strategic opportunities for Advanced Generation RD&D and is summarized here.

Policy Framework

Significant California policy goals and directives related to non-renewable electricity generation, large-scale or distributed, are:

- Statewide greenhouse gas (GHG) emissions will be limited to 1990-equivalent levels by 2020 (Assembly Bill 32 [Nuñez, Chapter 488, Statutes of 2006]).
- Reduce GHG emissions to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050 (Governor's Executive Order - S-3-05).
- Install 4,000 MW of additional combined heat and power capacity by 2020 (California Air Resources Board [ARB] AB 32 Scoping Plan).

- Use combined heat and power so that new construction is net zero energy by 2020 for residences and 2030 for commercial buildings (*2007 Integrated Energy Policy Report* [*2007 IEPR*]).
- By 2012, repower aging power plants or retire and replace with cleaner technologies (*2005 IEPR*).
- Phased elimination of once-through cooling between 2015 and 2021 (*2008 IEPR Update*).
- New reliance on power plants with CO2 emissions greater than 1,100 pounds per MWh, similar to those of a modern natural gas combined cycle power plant, is prohibited (*2007 IEPR*, SB 1368)
- Ensure that the citizens of this state continue to receive safe, reliable, affordable, and environmentally sustainable electric service (Senate Bill 1250 [Perata, Chapter 512, Statutes of 2006])

California policy goals include reducing emissions and environmental impacts from electricity generation. While there are no specific goals for efficiency in natural gas power plants, the state's primary source of generation, goals may be implied through generation emissions standards, as listed in SB 1368. Further, although the state has not yet developed specific targets or goals, it is interested in carbon capture and sequestration research.

Current Status of Advanced Generation Technologies

This paper covers 20 primary focus technology areas organized into five groups, and six secondary focus technology areas, organized into three groups, Table 8. The primary focus technologies directly pertain to PIER Advanced Generation. The secondary focus technologies are mainly addressed by other PIER research areas. However, Advanced Generation is participating in the research and coordination of the secondary focus technologies and is providing its support.

Table 8. Advanced Generation Technologies Profiled

Primary Focus Technologies	*Secondary Focus Technologies*
• Distributed Generation / Combined Heat and Power - Fuel Cells - Hybrid Fuel Cell Gas Turbine Cycles - Reciprocating Engines - Stirling Engines - Microturbines - Gas Turbines • Cooling / Combined Cooling Heating and Power - Absorption Chillers • Advanced Gas Turbine Cycles - Industrial Cogeneration - Inlet Cooling - Recuperation - Intercooled/recuperated - Heat recovery - Advanced Simple Cycle for Peaking - Hybrid Renewable Cycles - Integrated Gasification Simple Cycle • Replacement for Once Through Cooling - Dry Cooling - Wet Cooling Towers - Alternative Cooling Water - Hybrid Cooling Towers • Carbon Reduction - Pre-Combustion Capture	• Advanced Coal/Biomass Combustion - Integrated Gasification Combined Cycle - Ultra-Supercritical Pulverized-Coal - Supercritical Circulating Fluidized-Bed Combustion • Carbon Capture and Sequestration - Post-Combustion Capture - Geological Sequestration • Advanced Nuclear Power Generation

Source: *Navigant Consulting, Inc.*

Key conclusions from the profiles of each group of technologies are:

Distributed Generation/Combined Heat and Power

- Cost is still a limiting factor for widescale adoption of most distributed generation technologies.
- Combined heat and power is typically the most cost-effective application for distributed generation.
- There is a recent trend in research on fuel flexibility of distributed generation/combined heat and power systems, specifically targeting alternative fuels and other low-value fuels.
- There has been limited investment in communication and control technologies for distributed generation and combined heat and power systems that would ease integration with the smart grid.
- California Electric Rule 21–Generating Facility Interconnections (Rule 21) has been successful in removing interconnection barriers.

- Hybrid Fuel Cell–Gas turbine cycle systems have the highest efficiency among Distributed Generation technologies.
- A large amount of funding is going to transportation fuel cells, with limited research funding going to stationary power fuel cells.
- As transportation technology research becomes more focused on plug-in hybrid technologies and moves away from fuel cells, this could also lead to reduced funding for stationary fuel cell research.
- PIER and the Electricity Analysis Office are funding an industrial combined heat and power market potential study, as well as an update to the 2005 combined heat and power market potential study.

Cooling / Combined Cooling Heating and Power

- Absorption chillers are currently the primary technology used in combined cooling, heating, and power systems.
- Electric driven chillers are another important technology used in combined cooling, heating, and power systems.
- High cost, relative to the efficiency benefits, is the main barrier for widescale adoption of combined cooling, heating, and power.
- While overall combined heat and power efficiency is generally lower for systems paired with absorption chillers relative to other combined heat and power systems, the primary benefits of using the technology in warmer climates are effective usage of waste heat.

Advanced Gas Turbine Cycles

- Most of the advanced gas turbine cycle technologies are mature, and most new power plant projects typically incorporate these technologies.
- There is a significant opportunity to improve efficiency from existing power plants by retrofitting them with advanced gas turbine cycle technologies.
- In recent years, there has been limited research on developing new gas turbine cycle technologies; most of the research in these technologies was performed more than 10 years ago.
- There has been limited effort to demonstrate the benefits of the technologies in retrofit applications.
- Recent research has been primarily focused on materials, by the original equipment manufacturers.
- There has been a significant amount of research outside the United States on hybrid renewable systems that address the intermittency of renewables.
- While there are significant incentives in place for renewable systems, hybrid systems do not qualify for these incentives, and there are few incentives available for hybrid renewable systems.
- There is a large technical potential for industrial cogeneration and heat recovery that has not been realized.

Replacement for Once-Through Cooling

- Equipping power plants that currently use once-through cooling (OTC) with any of the alternative technologies may be expensive and may affect the plant efficiency.
- Older power plants will likely shut down as a result of the policy to eliminate once-through cooling.
- The cost of power plant cooling systems is highly dependent on the site.
- Typically, dry cooling is the most expensive alternative, followed by hybrid cooling, then closed-cycle wet cooling towers.
- Even though wet cooling towers can use sea water, they still represent a significant improvement over OTC since they use only a small percentage of the amount of water used in OTC.
- Space (for example, for cooling tower) could be a limiting factor in retrofitting some plants with an alternative cooling system.

Pre-Combustion Carbon Capture

- Cost of pre-combustion carbon capture systems (for example, systems that capture carbon before combustion) varies widely between new plants and retrofits.
- Cost of retrofitting existing plants with pre-combustion carbon capture systems is typically prohibitive.
- Cost of these systems is dependent on the amount of carbon in the fuel source; however, the cost/ton of carbon is still lower with a dirtier fuel (for example, coal), while the cost per megawatt hour (MWh) is lower with a cleaner fuel (for example, natural gas).
- Lack of utility-scale demonstrations has limited the adoption of this technology; the American Recovery Reinvestment Act of 2009 has allocated funding for utility-scale demonstrations.
- United States Department of Energy expects that new research on this technology could lead to significant cost reductions.
- Integrated gasification combined-cycle is a process that converts coal to gas that is used to power a gas turbine whose waste heat is passed to a steam turbine system. Integrated gasification combined-cycle with pre-combustion capture has the lowest energy requirements for capture, 0.194 kilowatt hour per kilogram (kWh/kg) of carbon dioxide (CO_2) processed, compared to 0.317 kWh/kg of CO_2 processed for natural gas combined-cycle plants with post-combustion capture.
- IGCC with pre-combustion capture shows the most long-term promise for carbon capture and sequestration (CCS).
- Little research has been done on pre-combustion capture for natural gas plants and opportunities exist, such as the use of integrated gasification simple-cycle (for example, process that uses exhaust heat to chemically reform fuel feedstock, typically natural gas, into a higher calorific flow fuel stream containing a significant concentration of hydrogen).

- The success of pre-combustion carbon capture technologies will depend on the success of carbon sequestration technologies.

Advanced Coal/Biomass Combustion

- There is limited electricity generated from coal in California; however, 17 percent of power consumed in the state is imported from coal power plants outside the state.
- The Energy Commission has invested some resources, but relatively much smaller than United States Department of Energy (DOE) investments, for the development and demonstration of advanced coal/biomass combustion technologies.
- Repowering old coal plants that export power to California with advanced coal combustion technologies could provide a significant carbon reduction opportunity.

Carbon Capture and Sequestration

- The opportunity for carbon capture and sequestration in California is mostly tied to natural gas power plants linked to enhanced oil recovery.
- Post-combustion capture is better suited for retrofitting of existing power plants.
- Post-combustion capture technology is more cost-effective for coal plants than for natural gas plants.
- Post-combustion capture is more energy-intensive than pre-combustion capture.
- Post-combustion capture technology requires additional development and cost improvement.
- Compared to other carbon reduction approaches, carbon capture is more expensive.
- The success of oil recovery carbon sequestration depends on the alignment of interest between the oil producer and society's need to reduce carbon emissions.

Advanced Nuclear Power Generation

- Various advanced nuclear power technologies are competing for combined construction and operating licenses and will be the first nuclear reactors built in the United States over the last 20 years.
- The earliest a new nuclear reactor could be operational in the United States would be about 2016.
- The cost of building an advanced nuclear power plant in the United States is highly uncertain given that no nuclear power plants have been built recently.
- There is still no facility for nuclear waste disposal.
- Existing research abroad (for example, China) is focused on early-stage modular technologies.
- California's moratorium on building new nuclear power generation would have to be lifted to allow for new nuclear power.

Key Trends and Issues

Overall, California has significant electricity resources that are already cleaner but less affordable than the United States average. To reduce GHG emissions from electricity generation, the state has adopted a series of energy policies. Among these policies, the Renewables Portfolio Standard is estimated to reduce generation from natural gas by 20-45 percent by 2020 in one study.[7] A recent study in support of the *2009 IEPR* found that generation from natural gas could be reduced 15 percent by 2020 under existing state energy policy.[8] In either case, natural gas continues to play a role in electricity generation. California may need to replace/repower 66 aging gas power plants with a combined capacity of 17,000 MW (40 percent of in-state gas-fired power plants and 25 percent of all in-state capacity) by 2012. The scope/timeframe of this goal is under review.

As California confronts a limited water supply, 20 desalination plants have been proposed statewide. Improvements have lessened the thermal and pumping energy required for the desalination processes, but the energy intensity remains high. Energy and greenhouse gas emissions impacts will need to be considered when assessing desalination projects.

Zero net energy new construction initiatives by the California Public Utilities Commission (residential by 2020 and commercial by 2030) could have a significant impact on energy efficiency and distributed generation. Statewide smart grid initiatives are expected to increase the value of photovoltaic (PV) and other distributed generation systems; however, realizing the expected value will require coordinated involvement of various stakeholders. The state may need to overcome technical and non-technical challenges posed by the intermittency of renewable generation, both distributed and large scale.

Strategic Opportunities

A new vision statement for the PIER Advanced Generation program enables PIER Advanced Generation to play a key role in helping the state meet key policy goals. The preliminary vision statement is:

> *The PIER Advanced Generation program provides key RD&D that enables California to generate energy efficient, abundant, affordable, reliable, and environmentally-friendly electricity (and other forms of power) from small to large power plants, including distributed generation and combined heat and power, using clean non-renewable fuels and fuel flexibility capability in order to help reach the greenhouse gas emission reduction targets.*

Keeping with this vision, PIER Advanced Generation would focus on improving efficiency and reducing GHG emissions of large-scale and distributed generation systems fueled with clean fuels like natural gas and fuel flexible. Three main program areas are:

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[7] Source: Lesser, Jonathan, Paul Lowengrub, Spencer Yang. *A Mean-Variance Portfolio Optimization of California's Generation Mix to 2020: Achieving California's 33 Percent Renewable Portfolio Standard Goal -* DRAFT CONSULTANT REPORT. California Energy Commission, PIER Program. CEC-300-2007-009-D

[8] Source: Tanghetti, Angela, Karen Griffin, 2009. *Impacts of AB 32 Scoping Plan Electricity Resource Goals on Natural Gas-Fired Generation*. California Energy Commission. CEC-200-2009-011.

- Commercial combined heat and power/combined cooling, heating, and power systems – Support development of cost-effective combined heat and power and combined cooling, heating, and power systems for commercial buildings and their widescale deployment.
- Industrial combined heat and power /cogeneration systems – Support development of cost-effective industrial combined heat and power/cogeneration systems and their widescale deployment.
- Advanced Gas Turbine Cycles – Support development and widescale adoption of cost-effective advanced gas turbine cycles, including integrated hybrid renewable systems that significantly improve the efficiency and fuel flexibility of natural gas power plants.

Also, PIER Advanced Generation will continue coordinating and providing support while avoiding duplication of efforts and funding research addressed by other PIER research areas. For example:

- Residential single family combined heat and power/combined cooling, heating, and power systems – Technologies currently not cost-effective as thermal load too small relative to electricity load. Continue to monitor technology progress as there is a high technical potential for residential combined heat and power /combined cooling, heating, and power systems.
- Distributed generation systems primarily used for emergency baseload, peaking, backup, and cycling applications – Primary focus on more efficient, cost-effective, and environmentally friendly combined heat and power systems.
- Distributed generation/combined heat and power interconnection rules and standards – Addressed by smart grid research area of the PIER Energy Systems Integration program.
- Renewables, including management of intermittency issues through the co-location of renewable systems and traditional gas-fueled generation systems – Addressed by the PIER Renewable Energy Technologies program.
- Water use in power plants, including replacement technologies for once-through cooling – Addressed by the PIER Environmental Area and PIER Industrial/Agricultural/Water End-Use Energy Efficiency program.
- Carbon capture and sequestration – Primarily focused on coal fueled generation and addressed by US DOE. Continue to monitor cost-effectiveness of application to natural gas-fueled power generation as under the West Coast Regional Carbon Sequestration Partnership (WESTCARB) and relevant to California.
- Nuclear – Moratorium still in place. Continue monitoring advances in the nuclear technology.

Key Research Issues

In each target research area, PIER Advanced Generation is considering focusing on some key issues:

- Commercial combined heat and power/combined cooling, heating, and power systems – The primary issue is system packaging and integration. Market and regulatory mechanisms are a secondary issue, to complement the Energy Commission's combined heat and power program.

- Industrial CHP/CCHP Systems – The primary issue is system packaging and integration. Identification of cost-effective sites and market and regulatory mechanisms is a secondary issue, to complement the Energy Commission's combined heat and power program.
- Advanced Gas Turbine Cycles – The primary issues are new technology development of integrated hybrid renewable cycle systems and as new technology demonstration of advanced generation technologies. Market and regulatory mechanisms are a secondary issue, to support policy development.

Stakeholder Input

Stakeholder input is a critical element of the roadmap development process. Expertise in advanced generation technologies is widely spread across various stakeholder groups, including utilities, equipment manufacturers, research organizations, and policy makers. The roadmap development process involves seeking input from these groups.

5.3. Comments Received on Roadmap

As mentioned in Section 4.1.3, technical reviewers were invited to submit comments on the roadmap and the draft version of the Final Roadmap Report. Eight technical reviewers submitted comments, which are listed below.

5.3.1. Howard Lange and Al Baez (South Coast Air Quality Management District)

Comment(s):

1. There is little mention of environmental guidelines that the new power generation technologies should meet and no specific mention of NOx, PM and PM precursors (one of which is NOx). SCAQMD has ambient PM2.5 and ozone deadlines coming up in 2014 and 2023, respectively, both of which will be very difficult for us to meet. Since Southern California is such a large part of California's economy, it seem to us that one of the criteria for evaluating new technologies should be how clean they are relative to power production by a current new natural gas-fueled central plant, which would be the logical alternative to the higher-efficiency and more fuel-flexible technologies that your program will be fostering. For example, CARB requires that distributed generation technologies that do not require district permits meet stringent lb/MW-hr standards of NOx, CO and VOC emissions that are based on what modern central power plants now emit; and we have applied those same tough standards (a little less stringent on CO) to new IC engines used for power generation.
2. We agree that CCHP based on clean power generation such as fuel cells coupled with absorptive chillers is a potentially very useful program thrust area. This addresses year-around thermal load matching, which is critical for effective application of CHP. This could be further enhanced by facilities being able to export power to the grid at reasonable rates of return. This flexibility would improve the efficiency and emission benefits of CCHP. Perhaps the PIER program could explore barriers and possible

solutions in this area. Hopefully, results from the CEC project at UCI that is looking into thermal/electric load characterization of various categories of buildings *vis a vis* application of CHP can be factored into this area of the Advanced Generation Program.

3. There is a heavy emphasis on fuel flexibility and alternative fuels in the commercial and industrial sectors of the program plan as proposed. This is certainly in synch with what the state would like to do. However, while substantial progress is occurring in developing alternative fuels for vehicles (primarily natural gas), it is not obvious that there are any alternative (to natural gas) fuels that will be suitable for distributed generation that are expected to become available in any significant quantities. We think that to serve as a useful guideline the program plan should specify what alternative fuels CEC has in mind.

Response(s):

1. The policies mentioned in this paper are not comprehensive of all policies which guide PIER Advanced Generation efforts. The *Advanced Generation Roadmap Background Paper*[5] provides a more comprehensive list of policies.
2. PIER Advanced Generation RD&D is more focused on technology development than regulatory barriers. However, it should be noted that Rule 21 has been quite successful in removing interconnection barriers, and efforts related to grid interconnection issues, including Rule 21, are driven by PIER's Energy Systems Integration Area.
3. Roadmap milestones describe a state of industry or technological development forecasted to exist at a given point in the future, and is intended to cover broad range of technology and fuel types. Fuel type for specific projects will be considered and evaluated as PIER Advanced Generation implements the Roadmap and craft solicitations.

5.3.2. Steven Doyle (Clean Energy Systems)

Comment(s):

We request that you consider two topics for inclusion in the Roadmap which are not now there:

1. Advanced steam turbine technology (being accomplished by modifying gas turbines to operate with steam) is currently funded by DOE/NETL and has been supported by the CEC. We believe that with reference to advanced turbines, you could add as a Top Priority on your slide 5 "Reduced CO2 emissions from state-of-the-art turbines, as well as acknowledging on your slide 6 an entry in the 2012 timeframe for demonstration of steam/CO2 turbines, which we are assembling for testing now at the Kimberlina Plant, in Bakersfield.
2. In the Vision box on slide 6 you might consider adding a phrase, late in the paragraph, reading …"use of oxycombustion technologies. …"; as well as adding to Slide 15 a reference to oxycombustion programs in the Cross-cutting section at the bottom.

These additions would imply some modest editing of the narrative form of your Roadmap draft, but it should not be an excessive burden.

Advanced turbine developments are of high interest to the DOE/NETL and we believe to the Commission. Millions of dollars have been and are being spent on developing advanced steam turbine capabilities derived from former gas turbine configurations, such as the GE J79 and Siemens SGT900. These programs are in funded development, but unreflected in the draft Roadmap. In addition, the development of oxycombustion technologies for new boilers, boiler retrofits, advanced steam generating, non-polluting fossil fuel combusiton systems, and reheaters for use in advanced plants to increase plant efficiencies have been and are being funded. We feel it would be an unfortunate oversight for the Energy Commission Advanced Generation Roadmap to overlook and fail to even mention these relevant and important technologies.

Response(s):

Research into several of the specific technologies mentioned above could potentially be pursued in order to achieve the milestone "Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated". However, roadmap milestones describe a state of industry or technological development forecasted to exist at a given point in the future, and is intended to cover broad range of technology and fuel types. Specific technologies will be evaluated for further development as PIER Advanced Generation implements the Roadmap and crafts solicitations.

5.3.3. Donald Kendrick and Marty Kalin (Lean Flame, Inc.)

Comment(s):

1. Slide 5, Under Advanced Gas Turbine Cycles, “Cost Competitive Efficiency Technologies Options for Retrofit Applications Determined”, there was mention of three offerings that would be pursued under this task: (a) Inlet Cooling, (b) Reheat Cycles and a third that escapes me. Nowhere was there any mention of disruptive advances w.r.t. the combustion system which is obviously an integral component of the turbine and whereby there are needed and easy retrofit offerings that would enable sizeable efficiency gains. By way of an example, we at Lean Flame Inc. have a disruptive combustor retrofit product offering (Re-Circulating Vortex Combustor) that exhibits the following overall benefits which would complement the above efforts:
    - Increased Simple Cycle efficiency gains as a drop in retrofit
    - > 50% reduction is combustor system pressure drop relative to conventional combustors
    - Cleaner Technology - Ultra Low exhaust emissions (~2ppm @ 15% O_2): NOx, CO, UHC and Ultra low PM emissions
    - Obviates the need for back end clean-up strategies (SCR, etc.) and their associated costs
    - Reduces the requirements on Electrostatic Precipitators (ESPs) and their associated costs (liquid fuel GT)
    - Superior Operability Envelope – can operate at low (1atm) to high Pressures, low to high (sonic) throughput velocities, exhibits ultra low Lean Blow Out limits –

LBO (Fuel-air ratios at LBO as low as 0.0015) – almost an order of magnitude lower than conventional strategies

  - Fuel Flexibility – technology enabler for Alternative Fuels (low BTU/Biomass and/or hydrogen enriched) or oxy-combustion systems (mentioned by Steve Doyle)
  - Reduced Cost: Smaller, more robust burner for reduced fabrication and maintenance costs and increased system life
  - Superior Combustor Exit Pattern Factor (temperature profile) for increased turbine life
  - Reduced cooling flow requirements for further cycle efficiency gains

2. Slide 15, Budget Estimates:
    - I would recommend increasing the Advanced Gas Turbine Cycle budgets in the corresponding "Economic Viability of Efficiency Technology Options for Retrofit Applications" category to facilitate the above combustion/thermal efforts
3. There needs to be some mechanism to better facilitate demonstration and integration such new technologies at scale to fulfill these goals. I understand (Slide 16) that reviewers will be solicited from the appropriate industries (IPP, OEMs, Energy Services) but what will be the mechanism to engage at the field/product demonstration level which all milestones require? Hence there should be an aggressive push (incentives?) to engage utilities, end users, etc. now and not just as reviewers that will ultimately use the new advances such as building owners (for CHP systems), Utilities (for the Advanced Gas Turbine Offerings), etc.

Response(s):

The roadmap addresses high level technology options and is intended to cover a broad range of technology development options. The milestone "Cost Effective Technology Options for Retrofit Applications Demonstrated" is intended to address technologies for retrofit that will improve gas turbine cycle performance. Specific technologies will be identified during the implementation of this milestone and opportunities to propose the options suggested may occur under solicitations that are issued.

5.3.4. Kirk Woodside

Comment(s):

Within the Industrial Cogeneration top priority milestones it is important to add another conceptual element that needs to be addressed separately from those already mentioned, and that is gasification, preferably 'waste stream gasification'.

This is different and needs to be treated differently because the definition of 'alternative fuels' for a gasifier is vastly different than the ones presently considered by the plan. This is because the 'prime mover' can include the entire gasifier process facility with a DG backend.

This is where the industry, whether it is: food processing; lumber mills; an MSW facility or other source with an onsite waste stream- will be able to:

- recycle carbon containing materials into gas or liquid fuels or chemicals that can be reused onsite for heat, cooling, energy, or feedstock resources.
- where the definition of "alternative fuels" get dramatically enlarged when considered from the point of "alternative feedstocks"
- where co-firing of gasifier generated 'alternative fuels' can be cofired or blended with other 'alternative fuels' for boiler, chiller, turbine or engine combustion.
- where a 50 ton/day to 500 ton/day feedstock supply can be solely sourced from an individual industrial facility, or from a geographical industrial community. Blending of different feedstocks from industry or communities being able to provide local jobs, waste disposal, energy and fuel production for onsite or local (or exported) needs.

Stage of development:

Gasifiers are a proven technology for many feed stocks and are commercially available for specific feedstocks.

MSW gasifiers (a technology with which I am associated with) are operating with varying degrees of success in other countries. There are new technological developments that improve on an older design that was already functional in the demonstration of processing MSW at a rate of 300 tons / day over several years. The combination of these technologies provides for better control and alters the redox chemistry to provide higher BTU gas and more control over gas balance.

Early stage and commercial scale demonstrations can be part of the PIER program to provide the California demonstration sites necessary for testing of both the feedstocks and the DG potential. This could be an answer for much more than the 4000MW's that is a stated goal of the program.

The reduction of Climate Change gases is just a bonus.

Costs for a 50 ton/day system that can produce 3 MW/Hr with a turbine generator, would be in the range of $15-20 million over 2 years.

Response(s):

Roadmap milestones describe a state of industry or technological development forecasted to exist at a given point in the future, and is intended to cover broad range of technology and fuel types. Specific technologies and fuel types will be evaluated for further development as PIER Advanced Generation implements the Roadmap and craft solicitations. The specific project described above could be pursued in conjunction with several roadmap milestones including the commercial/industrial cross-cutting milestones, the "Impact of Alternative Fuels Use on CHP System Determined" milestones, and the "Standardized, Fully-Integrated CHP Systems Demonstrated for Key Sites and Applications" milestone.

5.3.5. Gerardo Diaz (UC Merced)

Comment(s):

My main comment with respect to the Roadmap report is that waste is only considered as waste heat. I do not see waste-to-energy as one of the research topics to pursue.

I guess it could be somehow associated to "fuel flexible DG technologies" or "alternative fuels use on CHP" but it seems to me that different sources such as biomass and agricultural waste, municipal solid waste, and sewage/manure/composting have a large potential to increase DG, lower greenhouse gas emissions, and reduce the load on saturated transmission lines.

On the same line of thought, gasification techniques are suitable for generating syngas from waste. In relation to this, it is not clear in the document if the topic of advanced turbines and microturbines is only related to natural gas or if it also includes operation with syngas.

Response(s):

Roadmap milestones describe a state of industry or technological development forecasted to exist at a given point in the future, and is intended to cover broad range of technology and fuel types. Targeted fuel types for fuel flexibility-focused projects will be evaluated as PIER Advanced Generation implements the Roadmap and crafts solicitations.

5.3.6. Jerald Cole (Hydrogen Ventures)

Comment(s):

I agree with everything I see in the roadmap. However, there are some major items that appear to have been overlooked.

1. The roadmap identifies power generation for possible desalination plants as an area to be addressed. However, what is not mentioned is power for the high speed rail system. The first leg of the high speed rail is scheduled to be on line by 2016 for testing and in revenue service by mid 2017. By my estimation, this will require the equivalent of one Solar Titan 130 gas turbine every ten miles along the track, which will be ramping up and down 12 times per hour all day long. This is a tremendous opportunity to explore advanced generation technologies that might be incorporated into this system. I have no specific suggestions at this time, but feel that it is imperative that consideration of the roughly 1200 MW of power needed for this project be factored into the advanced generation program.
2. It appears that Advanced Generation assumes implicitly that advanced generation will be as clean or cleaner than current electricity generation technology. However, that is not necessarily the case. I would like to cite the massive influx of peaking power plants that have been installed in California since 2001. These plants, when operating at steady state have incredibly impressive emissions figures. Unfortunately, for the most part they do not operate at steady state. During start up and shut down they operate with effectively uncontrolled emissions for thirty minutes or more. Even when up and running they perform a load following, or load leveling function and the emission control system cannot keep up when the turbine is ramping. As a result they are

regulated on a “rolling average” basis, sometimes putting out a lot of pollutants, while other times being quite clean.

Implementation of CHP and other advanced generation technologies is extremely likely to encounter similar issues. As such, I would strongly urge that advanced emission control technologies be factored into the Advanced Generation roadmap, less the entire exercise become futile. There are advanced emission control technologies in existence that have never yet been tried in most of the Advanced Generation scenarios and others in development that may be applicable. Note that I am NOT advocating that a separate program area be created to address advanced emission controls – rather I am advocating that anyone proposing a project under Advanced Generation be able to convincingly demonstrate that advanced emission control technology has been factored into their approach.

Response(s):

1. Potential applications for advanced generation technologies will be considered for further development and demonstration as PIER Advanced Generation implements the Roadmap and craft solicitations. Technology that would allow a gas turbine to efficiently ramp up and down continuously could potentially be researched in conjunction with the "Cost-Competitive Efficiency Technology Options for Retrofit Applications Demonstrated" milestone, however the application of such a technology would probably have to demonstrate applicability beyond the high speed rail project. Furthermore, applications of Advanced Generation technologies to transit applications may be considered as part of the PIER Transportation program.
2. Proposed projects under Advanced Generation will be evaluated and prioritized according to key considerations, one of which is how the project furthers progress toward policy goals. Since many policy goals are concerned with emissions levels for example (SB 1368, prohibits new power plants with emissions greater than 1,100 lbs CO_2/MWh, which is similar to that of a modern combined cycle power plant) Advanced Generation will be taking into consideration the potential impacts that proposed projects will have on emissions. However, the specific sets of criteria that will be used to evaluate a proposed project will be more fully developed and explained in the “Prioritize Near-Term Goals in Conjunction with the Annual Work Plan” step and the “Develop and Release Solicitations” step of the Roadmap implementation process.

5.3.7. Frank Verbeke (Alturdyne)

Comment(s):

Alturdyne was surprised to see that no “High Priority” technology developments or demonstrations were identified for the “Advanced Gas Turbine Cycles” program area. Alturdyne believes that the development of industrial/commercial gas turbine electric hybrids that use “ultra capacitors” to store and release quickly, high levels of electric power are short-term developments that have high probabilities of success and should be identified as high priority targets. Such a development would allow small ultra low emission gas turbines (100 to 300-kW) to replace large diesel engines (600 to 1000-kW) such as those used to power container cranes. In many instances regenerative braking can be used to recover much of the energy when a container for example is being lowered. Substitution of gas turbine electric hybrids for diesel engines will provide significant energy savings and much reduced air pollution.

A situation that occurs on building sites where machines are utilized sequentially with the early machines allowed to idle for many hours also could benefit from gas turbine electric hybrids but of a different kind. In such a scenario where diesel powered machines are used for a short time and then allowed to idle when a different machine takes its place could have their diesel engines replaced with electric motors and either batteries or ultra capacitors. A dedicated (self-propelled) charging system using a low emission small gas turbine generator set could be employed to sequentially charge each machine as they are "idled." This type of operation would reduce local criteria emission levels significantly and with the elimination of diesel engine idling would also provide large energy savings.

In addition Alturdyne believes that high priority should be given to the development of gas turbine systems that can utilize low Wobbe Index fuels such as those produced by air gasification of organic wastes. Air gasification is the least capital intensive approach to the conversion of solid wastes to combustible gases. Unfortunately conventional simple cycle gas turbines with high pressure ratios cannot "afford" the compression costs of gases with Wobbe Indices much lower than 300 and this has driven the use of costly oxygen gasification and pyrolysis systems. Gas turbines that could be used with low Wobbe Index fuels would be recuperated and have low pressure ratios. In addition the compressor and turbines would be "mismatched" in the sense that the compressor would supply a lower air flow than a conventional machine with the missing mass flow made up by the addition of the fuel gases. Such a development is urgently needed and is fairly straightforward and has a high probability of success.

Response(s):

Potential applications for advanced generation technologies will be considered for further development and demonstration as PIER Advanced Generation implements the Roadmap and crafts solicitations. Both High Priority and Medium High Priority milestones are being considered for implementation as part of the Advanced Generation Roadmap. Both of the projects listed above sound very promising and could potentially be pursued in order to help achieve different milestones. A project related to commercial/industrial gas turbine/ultra capacitor hybrid technology could be pursued in conjunction with the "Cost-Competitive Industrial CHP System Integrated with Energy Storage Demonstrated" milestone. Research regarding the modification of gas turbines to utilize low Wobbe Index fuels could potentially be pursued in conjunction with the "Fuel Flexibility Range for Key DG Technologies Established" milestone.

5.3.8. John Pratapas (Gas Technology Institute)

Comment(s):

1. If renewable fuels are included in the definition of "alternative fuels" used later, it is not clear where the boundaries are for Adv Gen versus Renewable Energy Program Areas.

2. It appears that reduction of GHG emissions is driving emphasis on fuel flexibility in CA? My impression is that the biggest barrier to fuel flexibility is environmental limits not technology. There should be opportunities to leverage the Energy Commission program with DOE programs to increase use of "opportunity fuels."
3. Using the word "assessment" in milestones seems like a study, rather than technology development.
4. With regards to the draft budget, this reviewer recommends that CEC consider funding level and match requirements tied to stage of development similar to NYSERDA as example below from their PON 1520:

   Project Funding – Three levels of project funding are available:

   - Research and development projects that will **produce a working prototype of a transportation product, system or service within 36 months**. NYSERDA's share of funding for any project in this class will be limited to a maximum of **$500,000**.
   - Research and development efforts that are crucial to the development of a marketable product, system, or service, but **will not result in a working prototype within 36 months**. NYSERDA's share of funding for any project in this class will be limited to a maximum of **$150,000**.
   - **Feasibility studies**, including, but not limited to preliminary studies such as conceptual design, technology and market assessments, and similar early-stage studies that are necessary precursors to ultimate product development and commercialization. NYSERDA's share of funding for any project in this class will be limited to a maximum of **$50,000.**
5. If PAC members do not receive any compensation for their expenses or time, what is benefit to them?

Response(s):

1. Fuel flexibility is intended to be a broad category. PIER Advanced Generation is primarily focused on natural gas and other non-renewable fuels, but there is significant opportunity to collaborate with PIER Renewables for the use of renewable fuels. However, Advanced Generation work in the area of renewable fuels would probably focus more on the modifications to the prime mover needed to allow it to utilize renewable fuels or leverage renewable fuel technology (e.g. solar collectors or concentrators) as opposed to work the focuses on renewable fuel technology itself.
2. This will be considered as projects are selected.
3. Applicable milestone descriptions have been rephrased to clarify the role PIER Advanced Generation would play in achieving those milestones.
4. The budget presented in this report is in draft form. This will be taken into consideration as PIER Advanced Generation finalizes its long-term budget.
5. PAC members and other advisors for PIER today play a crucial role in guiding PIER RD&D to ensure PIER is optimally managing its RD&D resources. While PAC members do not get compensated for their commitment to PIER, through their participation they

have an opportunity to provide important perspectives on how PIER RD&D funds should be utilized to address high-priority research needs, thus bringing benefit to the entire industry.